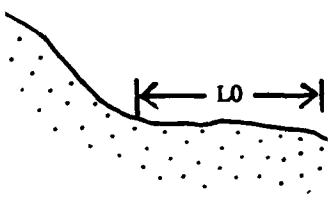
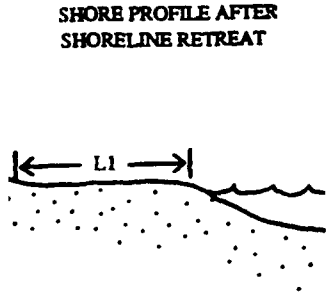
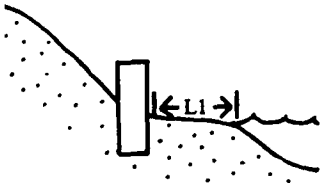
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BEACH RESPONSE TO THE PRESENCE OF A SEAWALL; COMPARISON OF FIELD OBSERVATIONS

by

James F. Tait, Gary B. Griggs

Department of Earth Sciences and Institute of Marine Sciences
University of California
Santa Cruz, California 95064

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Gary B. Griggs

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Coastal protection structures have historically been the most common approach to dealing with the problem of shoreline erosion in the United States. Three potential impacts of these structures have been identified and include: (a) impoundment or placement loss, (b) passive erosion, and (c) active erosion. The first two are relatively straightforward and predictable for the most part, whereas the third has been the subject of considerable discussion and debate but, until recently, has not been systematically investigated in the field. Four years of monitoring beaches adjacent to seawalls along the central California coast have allowed documentation of the seasonal beach changes that take place in response to the presence of seawalls, and also evaluation of some of the physical processes that influence these changes.

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PREFACE

The study summarized in this report was authorized by the Headquarters, US Army Corps of Engineers (HQUSACE). Research was conducted under Work Units 31232, "Evaluation of Navigation and Shore Protection Structures," Ms. Julie D. Rosati, Principal Investigator, and 32535, "Engineering Performance of Coastal Structures," Dr. Yen-Hsi Chu, Principal Investigator. Funds were provided through the Coastal Structures and Evaluation Branch (CSEB), Engineering Development Division (EDD), Coastal Engineering Research Center (CERC), US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The HQUSACE Technical Monitors were Messrs. John H. Lockhart, Jr.; John G. Housley; James E. Crews; and Robert H. Campbell.

Work was performed under the general supervisory direction of Dr. Chu, Chief, Engineering Application Unit (EAU), CSEB; Ms. Joan Pope, Chief, CSEB; Mr. Thomas W. Richardson, Chief, EDD, CERC; Dr. C. Linwood Vincent, Program Manager, CERC; Mr. Charles C. Calhoun, Jr., Assistant Chief, CERC; and Dr. James R. Houston, Chief, CERC.

This report was prepared by Messrs. James F. Tait and Gary B. Griggs, Department of Earth Sciences and Institute of Marine Sciences, University of California.

COL Larry B. Fulton, EN, was Commander and Director of WES during the publication of this report. Dr. Robert W. Whalin was Technical Director.

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BEACH RESPONSE TO THE PRESENCE OF A SEAWALL

Comparison of Field Observations

PART I: INTRODUCTION

1. Over the past several years, much attention has been focused on the impacts of seawalls on beaches. One reason for this is a body of opinion that such impacts are adverse and promote erosion. Pilkey (1981, 1988) has asserted that building a seawall dooms the beach in front of it. Other researchers deny this, asserting that such claims are not informed by an understanding of coastal processes (Dean 1988). Another reason for the recent focus on seawalls is that increased development of our coastlines has brought about a great deal of concern with shoreline erosion. In a time of sea level rise, the demand for coastal protection structures is understandably increasing. At present, our knowledge about the long- and short-term effects of seawalls on beaches is limited. Planners and decisions-makers are becoming more and more hesitant about granting permits or authorizing money for such structures while the issue of impacts remains unresolved. One of the principal complaints of the decision-making community is that not only are they being told one thing by some scientists and something else by others, but they are frequently being told different things at different times by the same scientists.

2. Central to this dilemma is the lack of sufficient field data with which to resolve the various claims. Most of our current ideas are based on theoretical or laboratory models. These models, however, have their own inherent limitations. The coastal environment is extremely complex and does not readily lend itself to reductionism. In order to be manageable, mathematical models rely on a number of strategic simplifying assumptions. In the study of seawalls, such assumptions as infinite length and perfect wave reflection have been used (e.g., Jones 1975). Similarly, the physical models often used by engineers (e.g., moveable bed experiments conducted in wave tanks or basins) face very serious problems with sediment and wave scale. Even when near-prototype scale wave basins are employed, the wave environment is often monochromatic, three-dimensional processes are not accounted for,

and, in general, reality is oversimplified. Furthermore, the results of such modeling are not usually checked in the field.

3. In part, the lack of good field data is due to a traditional reluctance of theoreticians to get their feet wet, combined with a resistance on the part of field workers to familiarize themselves with the theoretical debate. Principally, however, the lack of field results is a direct outcome of the high expense in both time and money that such studies require. Presently, a number of very good reviews of the seawall problem are available. Dean (1986) and Everts (1985) have authored speculative synopses which are both comprehensive and well reasoned. Kraus (1988) has reviewed the literature concerning laboratory, field, and theoretical studies and provides an excellent critique. The authors are indebted to Kraus for the references he has provided on field studies involving seawalls.

4. Although over 40 papers involving field observations and seawalls were reviewed by the authors, most of these studies were not focused extensively on the issue of the effects of seawalls on beaches, and so contained a minimum of relevant information. Several recent studies (e.g., Birkemeier 1980; McDonald and Patterson 1985; Kriebel, Dally, and Dean 1986; Kriebel 1987; Davis and Andronaco 1987; Sayre 1987; and Griggs and Tait 1988) have been addressed more directly to field observations of seawalls, however, these studies can only be regarded as a beginning. It is important to assess the effects of seawalls on beaches under a variety of conditions, using a variety of seawall designs, and in a variety of coastal environments (e.g., cliffed shore versus dunes, eroding shoreline versus stable shoreline, longshore transport versus no net longshore transport, high energy versus low energy, etc.). It is also important that enough seasons or years of record are available to be able to distinguish between long-term trends and short-term variability. Finally, there is a need to standardize the observations. The various effects should be enumerated and each effect studied in its own right. The processes responsible for or contributing to each effect should be identified and investigated. Controls on these processes should be defined. For example, what effects to seawalls have on the adjacent unprotected shoreline? What processes create these "end" effects? Which are most important? What controls the magnitude of their impact? Some researchers have found a correspondence between extent of end effects and length of a seawall; what physical processes does wall length influence? Why the apparent log spiral

shape to the end scour? Does it tell us anything about process? Lastly, we need to evaluate the significance of each effect. Some appear to be small in scale and/or ephemeral.

5. In October, 1986, Griggs and Tait (1988) began a two-year study of beach response to seawalls along northern Monterey Bay (Figure 1). The purpose of this paper is to compare the field results of Griggs and Tait with those of other field studies. Observed types of beach response to the presence of a seawall are examined. Quantitative information on the magnitudes of beach response, although scarce, is provided when available. Speculation by various researchers on the processes and controls involved is also reviewed.

PART II: BEACH RESPONSE

6. Beach response is the morphological transformation of the beach due to sediment transport. It is clear from the field studies reviewed for this paper that the response of a beach in front of a seawall to storm waves can be quite variable. For convenience of discussion, many of the types of beach response can be divided into two broad categories: "frontal effects" and "end effects." The following is a list of types of beach response which have been observed at seawalls (Figures 2 and 3):

a. Scour Trough - a linear trough or depression fronting a seawall.

b. Deflated Profile - the lowering or erosion of the beach face.

c. Beach Cusps - crescentic or semi-circular embayments on the beach face.

d. Rip Current Trough - a trough or embayment crossing through the surf zone.

e. End Scour - erosion of the unprotected beach adjacent to the end of a seawall.

f. Upcoast Sand Accretion - the impoundment of sand on the upcoast or updrift end of a structure.

Scour trough, deflated profile, and cusping are all examples of "frontal effects." End scour, sometimes referred to as "flanking," and upcoast sand accretion are examples of "end effects." Rip current embayments appear to be a more complicated case, affecting both the profile in front of the wall and the profile alongside the wall. Any of the above may occur as a response to wave-wall interaction. Or, beach response at a seawall may be indistinguishable from that on neighboring beaches which have not been modified by structures.

7. Although never observed in the field, certain hypothetical effects have been suggested by various researchers:

a. Steepened Slopes - increased beach face slope in front of a seawall.

b. Downcoast Shoals - shallow water depositional features downcoast from a seawall.

c. Reflection Bars - shore parallel bars offshore from seawalls.

8. While it is the authors' aim to clarify what actually happens to beaches in the vicinity of seawalls based on field observations, these

speculative effects are included for discussion so that other researchers may be aware of them.

Scour Trough

9. The presence of a scour trough in front of a seawall subsequent to a storm has been reported by a number of researchers (cf. Kraus 1988). As an erosional feature resulting from the presence of a seawall, such a trough represents either (1) formation of a trough in front of the wall which is not present along the adjacent natural beach or, (2) a deepening and/or widening in front of the wall of a regional longshore bar and trough system.

10. Sexton and Moslow (1981) report on the effects of Hurricane David (1979) on Seabrook Island, South Carolina (Figure 4). Their profile SEA-5 was positioned in front of a concrete seawall (Figure 5). Storm induced scour took the form of a broad trough approximately 30 m wide and 0.3 m deep. Erosion volumes of 10-15 cubic meters per meter of shoreline were reported for the structure-backed beaches. A neighboring profile, SEA-6, was positioned on a portion of the beach not backed by a seawall. No scour trough formed at this location. An erosion volume of 9.4 cubic meters per meter was reported for this profile, mostly in the form of foredune overwash. In this instance, dune erosion exposed the end of the seawall to flanking and the end segment collapsed.

11. The effects of Hurricane Elena in 1985 on west-central Florida have been reported by a number of investigators (Figure 6). Davis and Andronaco (1987, and Sayre (1987) both report the presence of a ridge and runnel system wherein the ridge was sometimes supratidal. This morphology developed regardless of whether or not a seawall was present. Davis and Andronaco noted that the largest and best-developed ridges and runnels were located in the northern part of the study area where exposure to high waves was greatest. Locally, however, erosion in front of seawalls was greater than erosion on adjacent natural profiles. At Sand Key, the beach elevation against a seawall (profile 7) was approximately 1.5 m lower than the beach elevation at a comparable location on a neighboring natural beach, profile 8 (Figure 7).

12. Sayre (1987) includes beach survey data both before and after the passage of Hurricane Elena on both seawall backed and unprotected beaches along Florida's west coast. Although the storm waves and surge associated

with the hurricane produced substantial beach erosion at all sites, the amount of erosion experienced on protected and unprotected beaches was not significantly different. Beach recovery was reported as being quite different, however, although there is not enough specific site data included in the report to fully assess cause and effect relationships. The two unprotected beaches recovered to pre-hurricane size within the next year or two. One of the seawall backed beaches, on the other hand, had not completely recovered within the 15 months following the hurricane and was artificially nourished. The second site appears to have experienced post-hurricane erosion, and incomplete recovery in the subsequent 14 months. The lack of specific site data, however (e.g. littoral drift and alongshore conditions, absolute elevation on profiles relative to mean sea level, position of seawall, extent to which waves actually interacted with seawall, etc.) makes it difficult to draw clear conclusions regarding the importance of the seawall in the beach recovery process.

13. In response to subsequent less severe hurricanes, the beaches fronting seawalls recovered the fastest in areas where large ridge and runnel systems were produced. Hurricane Juan, which came two months after Elena, actually caused the ridges to weld onto the storm beach. One seawall profile had no significant ridge seaward of it after Elena and retained an erosional profile until a nourishment project.

14. Kriebel, Dally, and Dean (1986), and Kriebel (1987) also reported on Hurricane Elena and its effects on the west-central Florida coast at Sand Key. Their objective was to measure modes and rates of post-storm beach recovery. Five profile lines were established: two in front of a seawall, one at the end of the wall where flanking was expected, and two in an area with reconstructed dunes and no seawall (Figure 8). The first profiles were obtained within 21 hours of the peak storm erosion and should be fairly representative of maximum storm effects. Unfortunately, no pre-storm profiles were taken. The dominant morphological feature identified by Kriebel et al. was a swash bar. This was undoubtedly the same feature that others had termed a ridge and runnel system. Profiles R-60 B and R-60 C, which were located in front of a seawall, showed clear toe scour when compared with profile R-60 A, located approximately 30 m north of the end of the wall. The sand level in front of the wall on profile R-60 B was 0.5 m lower than the sand level at a comparable position on the natural profile. The sand level in front of the wall on profile R-60 C, the southern-most profile, was 1.5 m lower than the

sand level on profile R-60 A (Figure 9). The differential scour in front of the wall has been attributed by Kriebel et al. to the fact that the wall is angled toward the surf and is therefore further seaward at the southern end.

Deflated Profile

15. Despite the preceding examples of scour troughs forming at seawalls as the result of hurricane-induced erosion, such troughs have not been reported elsewhere. Two years of biweekly monitoring of beach changes in the vicinity of seawalls in the Monterey Bay area of central California by Griggs and Tait (1988) revealed no scour trough formation despite the presence of very large storm wave in December of 1987, and 3 m waves in March of 1987. This does not mean that excess scour did not occur in front of the walls. Rather, it took a different form. Four study sites were monitored in which beaches in front of different types of seawalls were compared to neighboring beaches without walls. At three of the sites, a wide summer berm was present in front of the wall at the onset of monitoring. With the onset of erosive winter conditions, but before the waves had reached the seawalls, the beach was initially cut back uniformly alongshore. When the waves began to interact with the walls, however, the mode of erosion in front of the wall changed from one of parallel retreat to one of profile deflation. The berm was eroded sooner in front of the seawalls due to scour from the reflected waves. Differential erosion resulted in a flat, dissipative profile in front of the wall while a berm profile persisted seaward of the position of the wall on the adjacent natural beach (Figure 10).

16. Another way of describing this type of scour is to say that the topographic contours of the beachface migrated landward in front of the wall. The difference in sand level elevations in front of the wall and at comparable positions on the natural beaches ranged from 0.6 m to 1.2 m. This vertical offset is comparable in scale to that recorded for scour troughs. Profile deflation of this sort was characteristic of beach retreat in front of seawalls in the Monterey Bay area and was observed qualitatively in other locations. This pattern was particularly evident at New Brighton State Park, an area just upcoast of three of the monitored sites (Figure 1). Figure 11 shows a deflated profile fronting a long rip-rap revetment which protects back beach

development. Where the wall ends, this flat profile is immediately replaced by a wide berm profile.

17. One critical difference between scour in the form of a scour trough and scour in the form of berm profile deflation is that the persistence of the hurricane induced scour trough would appear to be dependent on the rates and effectiveness of post-hurricane beach recovery processes. Berm profile deflation, however, appears to be limited by the duration of the winter erosional phase itself. At every site in the Monterey Bay study, once the berm crest had migrated landward of the position of the wall, the profile in front of the seawall became generally indistinguishable from the profile on the natural beach (Figure 12). Thus, the period over which a deflated profile existed in front of the seawalls monitored (relative to the adjacent unprotected beach) typically only persisted for several weeks.

18. One interesting feature of the scour patterns observed by Griggs and Tait is that changes were focused well above the mean sea level intercept. Most of the scour took place between the +2 and +3 meter contours. Maximum volume of excess scour via profile deflation were approximately 20 to 30 cubic meters per meter of shoreline. This is consistent with the observations of Chiu (1977), who studied the impacts of Hurricane Eloise (1975) on the northwest coast of Florida. Chiu noted that the MSL line actually advanced seaward while the maximum retreat occurred at the +10 ft contour. Also, Chiu's surveys showed no bar formation, similar to scour witnessed by Griggs and Tait. Chiu suggests that the profiles may not have been surveyed soon enough after the storm, or that the storm moved so quickly that no bar had time to form.

Beach Cusps

19. In the study of Griggs and Tait, beach cusps were sometimes found in front of seawalls while being completely absent from the adjacent natural beaches. Typical spacings were on the order of 25 to 30 m and typical maximum vertical relief was from 0.1 to 0.3 m. Occasionally cusps with spacings of 50 m and vertical relief of 0.7 m were observed at Corcoran Lagoon, the steepest of the four beaches (Figure 1). The preferential formation of cusps in front of seawalls appears to correspond with that period of time for which a deflated profile exists in front of the wall relative to the adjacent natural profile.

Rip Current Embayment

20. McDougal et al. (1988) have suggested, on the basis of wave tank experiments, that rip currents tend to form at the ends of seawalls when the waves interact with walls. The result is a lowering of the profile locally and offshore transport of littoral sediments. The only field studies to date which mention rip currents in connection with seawalls are the littoral observations made by Griggs and Tait. An intermittent but persistent presence of rip currents at the downcoast ends of the South Beach Drive and Aptos Seascape seawalls was observed. In addition, the beach in front of the walls, when such a beach existed, was generally narrower at this point. The authors believe, at least in part, that this is due to the linear plan of the wall interacting with a gently curved shoreline.

End Scour

21. End scour, frequently referred to as "flanking," has long been recognized as one of the hazards associated with seawalls. It is recognized by engineers and has been documented (although not in sufficient detail) in the scientific literature. Like frontal scour, end scour is defined in terms of an excess beyond the natural erosion caused by the presence of the structure. McDougal et al. (1987) have characterized this scour as having an across shore dimension, "r," and alongshore dimension, "s" (Figure 13). One of the interesting aspects of such scour is the distinctive crescentic or log spiral form it often takes. This shape has been explored by numerous writers and is frequently associated with the development of headland bays (Silvester 1974).

22. Sexton and Moslow (1979) positioned one of their profiles (Sea-6) at the north end of a seawall on Seabrook Island (Figure 4). The profile was backed by dunes. Hurricane David leveled the foredune ridge on this profile causing 9.4 cubic meters of erosion per meter of beach front. This led to the exposure of the landward side of the wall to swash and flooding, and to the eventual collapse of this end of the wall. Deposition of the sediments occurred mainly in the form of a dune washover fan, although some material was deposited at the beach toe. The planimetric scour pattern had the characteristic log spiral shape. It is not clear from the paper whether or not return walls were employed. Sexton and Moslow made some careful notes of the wave

and beach conditions during this erosion event. Mean grain size was 0.125 mm, beach slope was from 1:25 to 1:30. The profile was located on the open coast and hindcast waves were 4.5 to 5.0 m before shoaling. Tides were 2.7 to 3.1 meters with a storm surge of 0.9 m.

23. Chiu (1977) investigated the effects of Hurricane Eloise (1975) on the northwest coast of Florida. Results from Walton and Bay counties show an average retreat for the dune toe of 20 m for profiles influenced by the presence of structures (i.e. profiles immediately downdrift from the structures). By comparison, the average dune toe retreat for profiles not influenced by structures was 17 m.

24. Birkemeier (1980) investigated the effects of structures and lake levels on bluff and shore erosion along Lake Michigan (Figure 14). One site was a 1.6 km reach backed mainly by sand bluffs. This reach also contained a 579-m long seawall with a shorter, 91-m seawall just upcoast. Birkemeier noted progressive scour at the downcoast end of the 579-m wall. There was also active bluff recession in this area. He quantifies this by stating that there was a 380 percent increase in volume eroded downdrift over expected recession based on profiles surveyed on a neighboring upcoast study site. He noted that the exact effects of the seawall on the downdrift cut were hard to assess because construction of yet another wall in the area of the downdrift erosion produced a second cut to the south of the first.

25. End scour also occurred at the downcoast end of the smaller wall. This small stretch of beach was backed by sand dunes. Erosion of beach and dune continued until an equilibrium was found accompanied by a "stable," crescent-shaped form often found on headland bays.

26. Kriebel, Dally, and Dean (1986) and Kriebel (1987) located one of their profiles 30 m north of the end of an exposed seawall (Figure 8). After Hurricane Eloise (1985) had raked the coast of west Florida, they report that their profile R-60 A showed "no additional erosion or flanking that might be expected downdrift of the seawall" (Figure 9). In other words, although the profile was only 30 m from the end section of a seawall, there was no difference in this profile and others up to thousands of meters away.

27. Walton and Sensabaugh (1979) examined an extensive set of profiles taken along the Florida panhandle coast before and after Hurricane Eloise in September, 1975. End scour or flanking was considered a common problem and

the authors sought to establish a relationship between the cross shore extent of scour and the length of the seawall (Figure 15).

28. In their study of seawalls along northern Monterey Bay, Griggs and Tait (1988) found that scour was often significant at the downdrift ends of walls. At the end of the Aptos Seascape wall, during the first year of the study, an arcuate area of scour extended past the ends of the return walls all the way to the base of the seacliff, a distance 75 m landward from the front of the seawall. The downcoast extent of scour lengthened during the first year of study, eventually reaching 150 m (Figure 16). It is interesting that much of this scour took place above the mean sea level contour and is not adequately reflected in statistics of MSL shoreline change. Unfortunately, this end scour propagated into the area being surveyed to obtain "natural profiles" for comparison. End scour also occurred at the South Beach Drive site which had a cross shore extent of 46 m and a downcoast length of 120 m. The principal differences appear to be that the Aptos Seascape wall is much further seaward on the beach profile, and that the return wall is more reflective and at an oblique angle to the shoreline.

29. It is not possible to plot these values on the graph developed by Walton and Sensabaugh, however. The recession distance (y) for the Aptos Seascape wall is approximately 50m, which exceeds the values on their y axis significantly and plots well beyond their upper limits for flanking. In the case of South Beach Drive, a continuous seawall or revetment extends upcoast for over 1000 m, which again would plot well beyond the limits of their plot.

Sand Accretion

30. When a seawall is built on a shore which is experiencing long-term erosion, has large seasonal fluctuations in beach width, or is subject to severe storms, shoreline retreat may cause the wall to project into the surf zone to an extent sufficient to interrupt the longshore transport of sediment. In effect, it may begin to act as a groin. In the field studies literature, only Birkemeier (1980) and, to some extent, Griggs and Tait (1988) discuss this effect. Quantitative data on volumes trapped, longshore transport rates, original position on profile, shoreline variability, etc., are scarce.

31. Birkemeier notes that the 579-m long seawall was constructed during his 1970-1974 study (Figure 14). At the time, no beach existed in front of

the sand dune area. After the longer wall was installed downcoast, the area in front of the dune gained a beach up to 30 m wide. By contrast, the beach in the area immediately downcoast from the wall narrowed from 11 m to zero.

32. Observations by Griggs and Tait (1988) noted a partial groin effect at the upcoast end of the Aptos Seascape seawall. During the winter months, when the berm on the control beach had retreated landward of the seawall, there would be a deflection in the berm crest such that it extended further seaward next to the end section of the seawall. This groin effect was not pronounced, however, as the position of the berm crest during the winters of study was only 10 to 20 m landward of the seawall at this location.

33. An additional aspect of beach accretion is the nature of the post-storm or spring recovery process. The studies of Davis and Adronaco (1987), Kriebel, Dally, and Dean (1986), Kriebel (1987), and Sayre (1987) of the impacts of Hurricane Elena on the west-central coast of Florida support the notion that impacts of seawalls on beaches are generally remedied during the recovery phase. Davis and Adronaco remark that beaches backed by walls suffered more erosion than adjacent natural beaches, but that these same beaches recovered the most rapidly. This observation was supported by Kriebel (1987). Dean (1986) states that there is no field evidence for delayed post-storm recovery due to wave reflection in the form of offshore deposits in front of walls or shoreward migration of bathymetric contours in the data of Kriebel et al. (1986). He further states that the Hurricane Elena data "support an equally rapid or nearly equally rapid recovery adjacent to coastal armoring."

34. Griggs and Tait (1988) in their study of four seawall-backed beaches in northern Monterey Bay, found that the recovery phase of berm rebuilding was "independent of any protective structure, resulting in a continuous, uniform alongshore berm crest." In August of 1988, the summer berm in front of the Aptos Seascape wall (a seawall built 75 m seaward on the beach profile from the base of the bluff) was wider than it has been at any time since their study began in October, 1986 despite significant storms during the winter of 1987-1988.

PART III: HYPOTHETICAL EFFECTS

35. There are a number of morphological changes which have been hypothesized, but which remain conjectural because they have not been documented clearly in the field. These effects are outlined here because various investigators have predicted their existence.

Profile Steepening

36. Pilkey (1981) has stressed that the presence of a seawall on the beach leads to steepening of the offshore profile. The eventual result of this is to make it more and more difficult for a beach to be maintained in front of the wall. Dean (1988) disputes this claim, however, saying that the only sense in which the profile steepens is by virtue of sediment being maintained at a high elevation behind the wall, an artificial steepening of the gross profile. There is almost no field data available to support or refute either assertion.

37. Fitzgerald (1980) reported on beach response at Yirrell Beach, northeast of Boston Harbor, to storms in February 1978 and January 1979. During the February storm, beach elevation in front of seawalls rose 1.0-1.5 m due to deposition of moderately sorted coarse sand until the wall was overtopped. Fitzgerald believes this sand was derived from erosion of the beachface. Profiles from the January storm reveal net erosion of the beach, accretion along the upper berm (especially next to the seawall), and thus an overall steepening of the profile. This could be thought of as steepening by back-beach accretion.

38. On the other hand, Kraus, Gravens, and Mark (Kraus 1988) examined four profiles along the heavily-walled northern New Jersey coast. These profiles had been surveyed over a period spanning thirty years. The results indicate that the profile shapes have remained stable with the equilibrium shape being controlled by the coarser sediments.

39. Griggs and Tait (1988) found that the profile shape tends to flatten in front of the wall when profile deflation, as described earlier in this paper, is occurring. Once the berm crest has retreated past the location of the wall, however, beachface slopes fronting the seawalls are indistinguishable from those on adjacent natural beaches (Figure 12), with the

exception of the beach immediately in front of the seawalls (20 to 30 m) which is typically slightly steeper and higher (Figure 17).

Downcoast Shoals

40. A number of researchers have argued for the existence of increased longshore current velocities and higher sediment mobilization in front of seawalls (e.g., Walton and Sensabaugh 1979, Silvester 1977). Considerations of sediment continuity suggest the existence of areas of deposition downcoast from the seawall once higher current velocities abate.

41. Birkemeier (1980) measured longshore current velocities in the vicinity of a seawall during a 1976 storm using dye as a tracer. The current in front of the seawall was twice as fast as the upcoast current and three times as fast as the downcoast current. No shoals were identified downcoast, however. Birkemeier speculated that any sand deposited may have been accreted to the downcoast beach.

42. No obvious shoaling appeared in the profiles surveyed by Griggs and Tait (1988). It is possible that their coverage did not extend far enough downcoast to detect this effect. *It is also possible that any excess sediment* transport in front of the wall could be masked by offshore transport due to rip currents at the downcoast ends of the walls.

Reflection Bars

43. If water depth in front of a seawall is sufficient for reflection of unbroken waves, laboratory models suggest that a standing wave may be generated beneath which the substrate forms bars at the nodes and troughs at the antinodes (cf. Kraus 1988). Dean (1986) notes that "while wave reflection can cause shore parallel bars in the laboratory, primarily for monochromatic waves, the existence of reflection bars in nature does not appear to be well-documented or at least highly prevalent."

44. The authors could find no reference to reflection bars in the field literature. Griggs and Tait (1988) found no clear evidence of reflection bars despite biweekly surveys of numerous walls. In fact, the reflection of an unbroken wave from a seawall may be an exception rather than the norm.

PART IV: PROCESSES

45. A variety of processes have been invoked to explain beach response to the presence of a seawall. Most of these have not been monitored in the field and so remain speculative. The following list has been compiled from the literature (cf. Kraus 1988).

a. Increased Sediment Mobilization.

b. Wave Reflection.

c. Sediment Impoundment.

d. Acceleration of Longshore Currents.

e. Rip Currents.

f. Wave Refraction and Diffraction.

g. Edge Waves.

Increased Sediment Mobilization

46. Many of processes proposed for creating scour at a seawall include a scheme for increased sediment mobilization. Everts (1985) and Walton and Sensabaugh (1979) argue that one mechanism for this is the concentration of wave energy in front of a seawall. Essentially, wave energy is dissipated over a smaller area in front of the wall and over a greater area on a natural beach. Everts (1985) asserts that because of this "large quantities of sand may be mobilized at the toe of the structure."

47. Another mechanism proposed for increasing sand mobilization is the effect of reflected waves interacting with incident waves. If the reflection is oblique, an interference pattern (Figure 18) of short-crested waves is created (Silvester 1977). This system has higher wave heights due to constructive adding of segments of the incident and reflected waves. Lin et al. (1986) have demonstrated that under laboratory conditions sediment mobilization is increased due to orbital motions in the higher waves created in a short-crested system.

48. Walton and Sensabaugh (1979) have also suggested that greater water depths in front of seawalls generated by scour and wave interference, combined with a lack of percolation, serve to increase pore pressures in the substrate. This "fluidizes" the sediments making them more susceptible to erosion. No measurements of suspended sediment concentrations in the vicinity of seawalls

have been reported in the literature such that the importance of this process has not yet been determined.

Wave Reflection

49. Sediment transport due to wave reflection is perhaps the most commonly cited process in seawall-beach interaction. Griggs and Tait (1988) attribute the selective seasonal profile deflation which can occur in front of seawalls to observed wave reflection (Figure 19). The reflected waves appear to move the sand seaward where it is removed from in front of the seawall by longshore currents. A small amount is also moved shoreward against the wall. No seaward accumulation of sediments was detected, however.

50. In describing the effects of older seawalls on the Pacific coast of Japan, Toyoshima (1978) asserts that during storms "incident waves were violently reflected on the steep front of seadikes. Foreshore and toe of seadikes were washed out with the reflected waves." Fitzgerald (1980), in his study of the effects of a nor'easter on the Massachusetts coast, attributed erosion next to seawalls to "wave reflection and offshore transport." He also mentions "catapulting" of sand over the seawalls by the wind. McDonald and Patterson (1985) comment that once waves significantly impinge on a seawall, a combination of wave reflection and longshore currents cause scour at walls.

51. Although the process of wave reflection is frequently cited, there is disagreement about its effects. Dean (1986) has stated that while "increased wave reflection can clearly occur as a result of coastal armoring, there does not appear to be a mechanism for an associated offshore transport to significant depths nor is there evidence to support such transport." In contrast, Everts (1985) asserts that waves reflected from a seawall "will act to transport the sand which was mobilized by wave energy concentrated at the toe of the structure. As the energy in the reflected wave increases, the capacity of that wave to cause seaward-directed cross-shore transport increases, and the distance the sand is transported seaward increases." Clearly, the lack of field observations and measurements of this process has hampered our understanding of it.

52. Wave reflection appears to be important at the ends of seawalls as well as in front of them. Griggs and Tait (1988) attribute much of the end scour observed in their study to alongshore sediment transport by waves

reflected from the end walls (Figure 19). This notion is in agreement with Everts (1985) speculation that return walls "may accelerate erosion at adjacent beach sites by reflecting waves in an alongshore direction."

Sediment Impoundment

53. One of the most serious effects of seawalls on beaches is the impoundment of sand. There are two basic mechanisms discussed in the literature by which a seawall impounds sand. One is through the permanent removal of sand from the beach system when the seawall is initially constructed. This removal of sand from the littoral budget has been underscored by Kraus (1988), Birkemeier (1980), and Walton and Sensabaugh (1979), among others. Dean (1986) has developed this argument the most thoroughly. He asserts that during a storm, there may be insufficient sand in front of the wall to "satisfy the demand" of the longshore bar for sediment. This will result in excess erosion of the beach immediately in front of the wall. In addition, erosional stress is placed on the neighboring foreshore as sediment is drawn into the lower area in front of the wall. The additional volumetric scour in front of the wall will be less than or equal to the amount that would have been provided by the upland beach and dune if the structure were not there. Everts (1985) notes that to the extent that a seawall denies material for bar formation, it also increases the incident wave energy. This is because a longshore bar will normally reduce incident wave energy by causing the larger waves to break prematurely at some distance from the shoreline.

54. In the study by Griggs and Tait (1988), however, while the berms on adjacent control beaches continue to retreat landward behind the line of the seawall, profiles fronting the seawalls never indicate any excess erosion relative to adjacent unprotected beaches.

55. A second type of sediment impoundment could be termed the "groin effect." Dean (1986) notes that "if an isolated armored segment is constructed on an eroding shoreline where a substantial longshore sediment transport exists, the armoring will in time project into the surf zone and will act as a groin to block the net longshore transport. The annual deficit of sediment downdrift of the armoring will be the sum of that blocked by the projecting armoring and that not yielded by the upland protected by the armoring."

He also points out that, on an eroding shore, the effects of upcoast impoundment will increase with time.

56. Griggs and Tait (1988) observed upcoast impoundment at the Aptos Seascape site in Monterey Bay (Figure 1). They argued that this groin effect produced scour at the downcoast end of the wall. They found it difficult to assess the impact of this impoundment, however, because downcoast scour was also caused by wave reflection from return walls (Figure 19), and possibly by the presence of rip currents. One interesting aspect of the observations of Griggs and Tait is that a groin effect can have an impact on a stable beach provided the wall is built well seaward on the beach profile.

Acceleration of Longshore Currents

57. Another possible process at work in the vicinity of seawalls is an acceleration of longshore currents. This process has been discussed by Everts (1985) and Walton and Sensabaugh (1979). Everts states that a seawall which projects into the surf zone "may increase sand transport in front of itself because the structure confines wave and wind-generated longshore currents into a zone narrower than the transport zone seaward of adjacent natural beaches."

58. McDonald and Patterson (1985) report the existence of a nearshore "gutter" in front of seawalls on the Gold Coast of Australia. This feature appeared after the installation of an upcoast groin. They note that this "gutter" often carried strong longshore currents and cite these currents as a major mechanism for scour in front of the walls. Birkemeier (1980) measured longshore current velocities in front of a seawall on Lake Michigan during a storm in 1976. The velocities were measured by dye injection. The upcoast velocity was 0.3 m/s, the velocity in front of the wall was 0.58 m/s, and the downcoast velocity was 0.18 m/s. While this constitutes field evidence that longshore currents can vary in the presence of a seawall, a more systematic and extensive study should be conducted.

Rip Currents

59. McDougal et al. (1987) investigated the role of rip currents in beach erosion at seawalls using a wave tank. The results indicated that rip currents had a strong tendency to occur at the ends of seawalls. When they

did, the magnitude of flanking erosion or end scour increased by a factor of two or three. Griggs and Tait made general littoral observations during their biweekly surveys. The strongest rip currents were often located near the downdrift ends of seawalls.

60. In the concluding portion of his review paper, Kraus (1988) comments that the alteration of longshore currents and sediment transport in front of walls may require clarification of the role of rip currents so that the full circulation pattern is taken into account.

Wave Refraction and Diffraction

61. In addition to wave reflection, wave refraction and diffraction appear to play a role in the development of end scour. In particular, the distinct log spiral shape which often characterizes end erosion at a seawall is a form which Silvester (1974) has demonstrated is the result of the combined processes of refraction and diffraction.

Edge Waves

62. Griggs and Tait often observed the presence of beach cusps on segments of beach that were backed by seawalls. These cusps did not appear on adjacent natural beaches. It seems reasonable to assume that these cusps are the result of the interaction of the waves and the walls, and that they would not be present under the same conditions if the walls were not there. At present, beach cusps are generally considered to be the product of edge waves generated along the shoreline. If this is indeed the case, then beach cutting by edge waves is another process promoted by the presence of a seawall.

PART V. CONTROLS

63. One of the most important things to understand about the seawall-beach system is what controls the type and magnitude of beach response. A major theme of this article is that beach response is variable because of the number of factors involved. Attempts to assess the potential impact of a seawall on the beach, then, should be site-specific. Furthermore, these factors are interrelated. Each factor influences other controlling factors. For example, the position of any individual wall on the beach profile is a function of shoreline change as well as engineering considerations. The impact that a wall designed for low reflectivity has on the beach depends on the magnitude of the wave energy that impinges on it, among other things. The following is a list of the basic controls which appear to govern seawall-beach interactions:

a. Long-Term Shoreline Trends (Erosion versus Stability).

b. Position of Wall on the Beach Profile.

c. Geomorphic Shore Type (Cliffed versus Dunes).

d. Sediment Supply/Width of Beach.

e. Relative Water Level (Tides, Storm Surge, Sea Level Rise, Land Subsidence/Emergence).

f. Sediment Properties (Grain Size, Fall Velocity).

g. Offshore Gradient/Width of Surf Zone.

h. Wave Characteristics (Height, Period, Breaker Angle).

i. Exposure of Coast.

j. Wall Design (Height, Permeability or Dissipative Characteristics, Slope).

k. Length of Wall.

Long-Term Shoreline Trend

64. The overriding factor in the impact of a seawall on a beach is the long-term trend in the position of the shoreline. If a shoreline exhibits an erosional trend, and some segment of that shoreline is fixed in position by a seawall, then the beach will eventually disappear in front of the wall. On a stable shore, the wall will only affect the beach when a large storm or large seasonal fluctuations in the position of the shoreline exposes it to wave attack. McDonald and Patterson (1985) conclude that on an eroding coast, the

seawall will move progressively further out on the beach profile until no beach exits. Dean (1986) points out that on an eroding shore, an isolated wall can project into the surf zone and block littoral drift. The impact on the beach gets progressively greater with time. Everts (1985) states that "on a coast where the shoreline is stable or slowly advancing, a PD (Protective Device or Seawall) is necessary for shore protection only when reversible changes in beach width exceed the maximum beach width. On a retreating coast, the influence of a PD on coastal processes increases as the beach width decreases. Waves will have an increasing access to the PD. Eventually, when a beach no longer exists in front of the PD, waves will begin to scour sand from the toe of the PD. Water depth will begin to increase and wave height at the PD will increase." It is in this latter situation, particularly on migrating Atlantic coast barrier islands, that Pilkey's position on the impacts of seawalls on beaches seems to be based. It must be recognized, however, that the Atlantic and Gulf coast situations are very different than the Pacific coast beaches studied in California by Griggs and Tait (1988), for example.

Position of Wall on Beach Profile

65. Another important factor, one which is related to the stability of the coast, is the position of the wall on the profile. The basic concept is that the more often and the more vigorously the waves interact with the wall, the greater the potential magnitude of beach response. This assessment has been echoed by numerous researchers. In their 20-year study of the effect of coastal protection structures on an Australian coast, McDonald and Patterson conclude that the impact of a seawall on the beach is "largely dependent on its position on the profile." Sato, Tanaka, and Irie (1968) came to the same conclusion based on laboratory studies of scour at a seawall in a prototype-scale wave basin.

66. Kraus (1988), after a thorough review of the literature, comments that the position of a seawall with respect to the surf zone is "a critical parameter controlling the amount of erosion and the beach recovery process." He also cautions that "this distance is variable because the boundaries of the surf zone shift according to tide, surge, and period and height of the waves." To the extent that a wall projects into the surf zone, it may serve to

constrict longshore currents as well as increase upcoast sand impoundment and the accompanying downcoast scour. The position of a wall on the beach profile may also affect water depth and wave heights in front of the wall. If a wall projects well into the surf zone, wave energy directed against the wall, and therefore depth of scour in front of the wall, could increase.

67. In their study which compared several seawalls, Griggs and Tait (1988) comment that the wall which projected furthest seaward was the first to lose the beach in front of it with the onset of winter waves, experienced the greatest scour or deflation, and was the last to recover during the summer months. It is interesting to note that a catwalk had to be built along the length of this wall because it is dangerous, if not impossible, to walk in front of it during winter wave conditions or during high tides.

Geomorphic Shore Type

68. One of the less obvious controls on seawall impacts on the coastline is the geomorphic shore type. Two extremes or end members of shore type might be sea cliffs versus lowlands with dunes, although these hardly exhaust the variety of world coastal geomorphology.

69. Griggs and Tait (1988) studied four beach sites in northern Monterey Bay. All sites were backed by moderately high (10 to 30 m) seacliffs, although the seawalls varied in their positions relative to the seacliffs, being up to 75 m seaward. It was apparent that a beach backed by a seacliff should behave quite similarly to a beach backed by a seawall if the cliff were composed of fairly resistant material. If the bluffs are relatively unconsolidated, they may be able to retreat rather swiftly, preserving the width of the beach. On cliffed shores, then, the seacliff geology can be an important factor. Goud and Aubrey (1983) have reported on seawalls built into the cliffs of the Cape Cod shore and state that they generally protect the cliffs without enhancing erosion.

Sediment Supply/Beach Width

70. A number of studies have indicated that sediment supply is an important factor in determining beach response to seawalls. Observations seem

to fall in two general categories: (1) width of the natural beach and (2) the impact of the wall on sediment sources.

71. In the first category, Kraus (1988) remarks that if a beach fronting a seawall is narrow, the recovery process may be absent. If a sediment supply exists, however, a longshore bar system can develop in front of walls in much the same way as on adjacent natural beaches or as would have occurred prior to wall construction. Fitzgerald (1980) observed that areas which suffered the most damage during the nor'easters he evaluated had a small high-tide beach in common. Dean (1986) reports that on a sediment deficient beach the profile may assume a lowered equilibrium shape. Kraus, Gravens, and Mark (Kraus 1988) add that on a sediment deficient coast, the profile may have an equilibrium shape governed by the coarser sediments.

72. In the second category, McDonald and Patterson (1985) report that the Gold Coast of Australia consists of a natural dune system which has been completely urbanized. Beach erosion has become, for a number of reasons, a serious problem. In an outlying area known as Burleigh, however, erosion into the dunes is unobstructed by seawalls and the beach remains in good condition. Komar (1983), in a case study of erosion at Siletz Spit in Oregon, points out evidence for a coupled beach and dune system which includes cycles of sediment transfer between the two. Komar also comments on the possible impacts brought about by armoring the bluffs of a beach compartment which has seacliff erosion as its principal sand source.

73. In general, restriction of sediment sources, whether from longshore transport or from dune erosion, can result in net shoreline retreat and effectively advance the position of the wall on the beach profile in a seaward direction.

74. Conversely, where ample littoral sediment exists and/or littoral drift rates are large, the potential for seawall impacts is greatly reduced. This situation has been documented along the shoreline of northern Monterey Bay by Griggs and Tait (1988) where the littoral drift rate is approximately 225,000 cubic meters/year and beaches are typically very wide and stable.

Relative Water Level (Tides, Storm Surge, Sea Level Rise, and Subsidence/Emergence)

75. A number of reports have indicated that water level exerts a tremendous influence on beach or seawall response to storms in general (e.g.

Fulton-Bennett and Griggs 1985; Griggs 1983, Komar and Wyrtki 1987). Carter, Monroe, and Guy (1986) cite lake level as the primary factor in lakeshore erosion along Lake Erie. Kraus (1988) comments that water level controls, in part, the position of the wall on the profile. Everts (1985) states that the maximum energy concentrated in front of a seawall "is a function of the water depth in front of the structure when the largest waves reach it." Factors such as tidal range, frequency and magnitude of storm surges, relative long-term sea level changes, and susceptibility to shorter-term changes such those associated with an El Nino "wave," should all be taken into account before a seawall is constructed.

76. As with a long-term reduction in the sediment supply, a relative rise in sea level (whether eustatic, or due to land subsidence) will result in a net shoreline retreat, effectively moving the seawall closer to the surf and narrowing the beach in front of the wall.

Sediment Properties

77. How a given current or turbulent flow will transport sediments is, in part, controlled by the properties of the sediment grains themselves. Grain size and grain density are two of the most important of these properties. They are often combined into a single parameter called fall velocity. Fitzgerald (1980) reported that morphologic changes due to the February 1978 storm near Boston, Massachusetts, were accomplished by the landward transport of gravel and coarse sand, and the seaward transport of medium and fine sand. At all profiles, accretion occurred where sediments were predominantly gravel. Erosion occurred where sediments were predominantly sand. Fitzgerald asserts that whether transport was onshore or offshore was determined by the fall velocity of the sediments. Dean (1986) contends that if wave and sediment characteristics are conducive to bar formation, that additional volumetric scour will occur in front of the wall. If, however, wave or sediment characteristics are not as conducive, then the profile will be controlled by the equilibrium slope for those sediments.

78. Fine-grained sediments are much more susceptible to mobilization and transport than are larger sediments. Although probably not a primary factor in beach response to seawalls, sediment properties should be considered

in a situation where a seawall is proposed for a location with a restricted sediment supply.

Offshore Gradient/Width of Surf Zone

79. In his 1988 review, Kraus states that "field observations of storm-induced erosion and post-storm recovery indicated that beaches backed by seawalls respond similarly to beaches without seawalls if a sufficiently wide surf zone was present...." Surf zone width is a function of wave height and offshore gradient. Fitzgerald (1980) notes that areas suffering the greatest damage in the 1978 storm had steep offshore gradients. Toyoshima (1978) sites beach loss in front of "seadikes with steep nearshore." Chiu (1977) studied storm damage from Hurricane Eloise (1975) in several counties in northwest Florida. He remarked that steeper beaches suffered greater erosion. No indication is given as to what constitutes a "steep" gradient in terms of greater beach erosion. The term appears to be used in a relative sense. In general, a steep offshore gradient allows larger waves to break closer to shore, resulting in greater swash excursions. In addition, a steep offshore enhances seaward transport of sediments by providing a high, seaward-directed component of gravity.

Wave Characteristics

80. Wave characteristics such as height, period, and breaker angle are all important factors in beach response. Kraus (1988) notes that wave period and height govern the boundaries of the surf zone with respect to a seawall. Birkemeier (1980) calls wave climate a an important "process factor" and mentions the dominant role played by "storm type" in beach erosion. Carter, Monroe, and Guy (1986) cite storm waves as the second most influential factor in erosion on Lake Erie. Sato, Tanaka, and Irie (1968) found wave steepness to be one of two control factors for scour at a seawall in their prototype-scale laboratory experiments. Dean (1986) points out that the magnitude of the groin effect produced by seawalls which protrude into the surf zone is dependent on the presence of a substantial longshore current which is in turn dependent on wave height and breaker angle. Wave parameters also appear to

determine whether or not a bar and trough system will be formed in front of a wall.

81. The downcoast scour or end effects observed by Griggs and Tait (1988) were due directly to wave reflection. Field observations indicated that breaker angle determined the path of the reflected wave, incident height determined the reflected wave height, and incident wave period determined how far downcoast the reflected wave propagated before interfering with the next incoming wave front.

Exposure of Coast

82. The study of the impacts of Hurricane David on Seabrook Island by Sexton and Moslow (1981) provides a good illustration of the effect of exposure on beach response. Although the authors remark that most of the erosion took place along beaches with seawalls, they also note that these were the most exposed to direct wave attack. The sheltered beaches along an inlet actually accreted during the storm. Fitzgerald (1980) listed exposure, along with offshore gradient and beach width, as principal factors governing coastal damage during the 1978 storm.

83. Although discussing coastal exposure separately from wave characteristics is a fine distinction, it is useful in that often the general wave climate is known for a storm but wave characteristics for specific locations may be difficult to determine.

Wall Design (Height, Slope, Permeability/Roughness)

84. One control discussed in a number of studies is seawall design. Walton and Sensabaugh (1979), in discussing the theoretical analysis of Jones (1975), point out that reducing the reflection coefficient of the wall (e.g. by sloping the surface or by placing a rip-rap apron at the toe) should reduce scour. Everts (1985) postulates energy concentration at the toe of a seawall is a function, in part, of the type of wall. "A smooth vertical wall without a sloping rock toe in front reflects the most energy and dissipates the least." Since a sloping, rough-surfaced or permeable wall should dissipate more of the incident wave energy, there should be less energy available for scour. In his review of the literature, Kraus (1988) finds that laboratory,

theoretical, and field studies all support the notion that there is less scour when the wall is less reflective.

85. An engineering field study by Toyoshima (1984) on the Pacific coast of Japan relates the changes in the shoreline subsequent to the replacement of an older, vertical seadike with a newer, sloping, rougher wall. The wall was replaced in 1982. In 1984, the author reports, "the shoreline has advanced substantially and the sand beach has grown extensively." It should be noted that no description of regional or long-term trends was provided.

86. Griggs and Tait (1988) investigated the significance of wall design as one of their research objectives. At north Beach Drive (Figure 1), a sloping rip-rap revetment abuts a vertical impermeable seawall. During much of the year of monitoring, a beach profile of low slope persisted in front of the vertical wall, while a relict berm remained in front of the less reflective rip-rap wall (Figure 21). It should be noted, however, that while both walls were hit by waves during the study, they are located at the back of the beach and were not hit frequently. In subsequent study, Griggs and Tait have examined the juncture of a vertical concrete seawall and a sloping rip-rap revetment along south Beach Drive (Figure 1). These walls are slightly further seaward on the beach profile (46 m in contrast to 35 m), are hit frequently by waves during winter months, and two years of bi-weekly surveying indicates the beaches in front of them have generally had indistinguishable profiles. In other words, although they should have considerably different reflectivities, there is no indication of this in the resulting beach profiles. Frontal wave reflection is observed at both walls at high tide.

Length of Wall

87. The hydraulic model studies of McDougal et al. (1987) indicate that the magnitude of end scour increases with the length of the wall. In laboratory tests, and in the field data of Walton and Sensabaugh (Figure 15), it was observed that the cross-shore extent of end scour is approximately 10 percent of the wall length. Several small scale model tests indicate that the downcoast extent of end scour is approximately 70 percent of the wall length. This control should be viewed with a certain amount of skepticism as the results of Walton and Sensabaugh show considerable scatter and the laboratory results of McDougal et al. have not been confirmed in the field.

88. Dean (1986) provides a possible physical explanation for the effect of wall length. He postulates that when sand is retained behind the wall, the remaining sand is insufficient to "satisfy the demand of the bar" so "erosional stress" is placed on the neighboring foreshore as sediment is drawn into the low area in front of the wall. The magnitude of this erosional stress is, then, proportional to the length of the wall, i.e. to the total percentage of sand that has been permanently removed from the littoral system.

89. Griggs and Tait (1988) observed an arcuate area of scour which extended 150 m downdrift from the end of the Aptos Seascape wall. This length of scour was approximately 50 percent of the length of the wall. Griggs and Tait argued that the distance the wall extends into the surf zone may be a more relevant factor than wall length if end scour is associated with upcoast sand impoundment or "groin effect." Wave period and height, breaker angle, and end geometry and reflectivity of the wall were also advanced as possible controls on end scour.

PART VI: DISCUSSION AND CONCLUSIONS

90. An examination of the available literature reveals that little field research has been conducted on the problem of beach-seawall interaction. Those few studies which do focus on the problem of beach response to seawalls indicate that beach response can be variable, and that a number of processes may be at work. Furthermore, the factors that may control the type and magnitude of beach response are numerous and interdependent. The studies of Kriebel et al. (1986), for instance, indicate the formation of a scour trough in front of the wall during hurricane conditions. Griggs and Tait (1988) on the other hand, never encountered a trough, but instead observed a more rapid retreat of the summer berm in front of the walls they monitored. Sexton and Moslow (1981), Birkemeier (1980), and Griggs and Tait all observed end scour at the downdrift ends of walls, yet Kriebel et al. (1986) observed no flanking effects in a downdrift area where it was expected. Kriebel et al. (1986) and Griggs and Tait found that beach recovery was approximately as rapid in front of seawalls as it was on adjacent natural beaches. One profile surveyed by Davis and Andronaco, however, retained its erosional shape and eventually required beach nourishment. The variability of beach response and the apparent dependence on a number of interconnected factors suggests strongly that any evaluation of the potential impact of a seawall on the beach should be made on a site-specific basis. A wide variety of controlling factors need to be addressed, not just a single criterion such as wall design.

91. More studies are clearly warranted, especially in light of the fact that the processes and controls involved are largely speculative, and have not be measured in the field. Measurement of parameters such as suspended sediment concentrations, sediment transport, and nearshore current fields in the vicinity of seawalls are necessary before prediction of beach-seawall interactions can be made with confidence. Kraus (1988) makes some excellent suggestions for future seawall studies and monitoring programs. To underscore the speculative nature of the processes currently being associated with beach-seawall interactions, Dean (1986) points out that a rational argument, based on momentum flux considerations, can be advanced to show that increased wave reflection at a seawall actually reduces sediment transport.

92. Perhaps the single most important factor in the potential impact of seawall construction is whether or not the shoreline is undergoing a net

long-term retreat, and, if so, at what rate. If net retreat is occurring, then eventually the beach in front of the seawall will disappear. Such retreat is a function of a deficit in the littoral sediment budget and/or relative sea level rise. Unfortunately, long-term trends in beach erosion can be difficult to detect. The magnitude of reversible seasonal trends can mask a slow but progressive long-term retreat. Geomorphic shore type plays a role in the impact of stabilizing a shoreline undergoing net retreat. If waves can erode an upland dune area, beach width can be maintained in the face of shoreline retreat. If, on the other hand, the beach is backed by seacliffs made of highly resistant rock so that the rate of seacliff erosion is much smaller than the rate of beach erosion, then the cliffs will tend to stabilize the shoreline retreat naturally. Construction of a seawall at the base of such a cliff, for example to reduce undercutting, should have little net effect on beach erosion (Figures 22 and 23).

93. Critical to the magnitude of the effects of seawalls on beaches is the position of the seawall on the beach profile relative to the surf zone If there is little net beach erosion, then a wall at the back of a wide beach will only be attacked by occasional large storms and have relatively little downcoast effect on the beach. On the other hand, a wall built out to the water's edge will have many opportunities to interact with the waves and may frequently project into the surf zone to block littoral drift (Figure 24).

94. One of the most significant impacts that a seawall can have on a beach is end scour. This may happen because the wall projects into the surf zone and obstructs longshore transport, or because of wave reflection from the return or end walls. Such end scour will lower the sediment elevations at the downdrift end of the wall and may expose the upland bluffs or dunes to intensified wave attack. Griggs and Tait note that end scour at the Aptos Seascape site lowered the back beach as much as 1 meter, and progressed during their first year of study as far as 150 m downcoast. Birkemeier (1980) noticed the same response to the wall which was constructed during his study of the Lake Michigan shore. Downcoast scour at this site was progressive with time, extending approximately 270 m downcoast. To further complicate matters, in order to mitigate this scour, additional walls were constructed in the scour area and these, in turn, promoted further extension of the scour.

95. Some examples exist in which the beach in front of a seawall was subjected to storm waves, eroded, and never recovered. Kraus (1988) has

attributed these incidents to wave energy focusing and a lack of sediment supply. He also raises the issue of the role of pre-storm morphology. Toyoshima (1978) cites several examples from the Pacific coast of Japan. In two cases, an eroding beach failed to re-establish itself after a typhoon. In one case, a "stable bathing beach" disappeared after a severe storm. Toyoshima ascribes this loss to wave reflection from vertical seadikes. Davis and Andronaco (1987) noted that the beach in front of one of the walls in their study (Figure 6, profile 3) retained its erosional profile until finally being artificially nourished six months after the storm. They relate the lack of recovery to the fact that the ridge and runnel system, which developed on all of the other beaches in the study area irrespective of the presence of seawalls, was absent from this profile. A deficient sediment supply may have played a role. Birkemeier (1980), in his study of erosion on the Lake Michigan shore, remarked that a 579-m long wall was constructed at one of his study sites during the study. He noted that after the wall was constructed, the beach disappeared in front of it and speculated that increased longshore currents in front of the wall and wave reflection led to the loss of the beach.

96. McDonald and Patterson (1985) state that the seawall at the north Kirra area of Gold Coast, Australia, prevents the beach from re-establishing itself. They do not speculate on the reasons for this, however. It is entirely possible that updrift sand impoundment by jetties (training walls) on the Tweed river is responsible for decreasing the sediment supply. It is interesting to note, however, that in the far downdrift area of Burleigh, erosion into the dune is unobstructed by seawalls and the beach remains in good condition. It is possible that by preventing the transfer of sediments between the dunes and the beach, a natural dynamic equilibrium is disrupted, resulting in beach erosion. Such a natural coupled cycle is noted by Komar (1983) in his study of erosion at Siletz spit in Oregon.

97. The main point to be extracted from these examples of "permanent" impacts of seawalls on beaches is that they occur, but the reasons are not understood. Some combination of deficient sediment supply, exposure to very large waves, steep offshore gradients, fine grain size, or narrow beach width in front of the wall may be responsible. Such incidents need to be placed into a regional context where long term beach change trends are known. In the mean time, it might be wise not to build walls in localities which exhibit the

above mentioned factors, particularly where the presence of a beach is necessary or highly desirable.

98. Another concern must be for the relation between seawalls and the location of rip currents. McDougal et al. (1987) have suggested, based on laboratory work, that rip currents tend to form at the end of seawalls, and that when they do, erosion at the downdrift ends of walls is increased by a factor of two or three. Littoral observations made by Griggs and Tait support the notion of rip current formation at the ends of walls. Komar (1983) has documented the important role played by rip currents in coastal erosion. The seaward flowing currents can be quite fast and will transport sand offshore. In addition, they tend to hollow out embayments which allow larger waves to come close to shore before breaking, and thus these embayments and the adjacent bluffs or dunes become a focus for wave erosion.

99. There is some evidence that making seawalls less reflective may serve to reduce their impact on the beach. In one instance cited by Toshima (1985), it appears that the replacement of an older seadike by a newer less reflective wall may have encouraged some accretion. The role of seawall design, however, is not well understood. The significance of a change in reflectivity is not clear. At one site, Griggs and Tait (1988) found clear differences in beach erosion between the beach in front of a vertical, impermeable structure and the beach in front of a sloping, permeable one. During subsequent study at another site, no significant difference was found between the beach in front of a sloping rip-rap revetment and an adjacent vertical concrete seawall, even though that site had been subjected to attack by moderate sized waves. It is possible that differences in reflectivity are significant only within a certain range of wave energies, and that large waves nullify any benefit conferred by those differences. It is also probable that differences in seawall reflectivity are more significant under approximately monochromatic wave conditions (such as those utilized in wave tank studies) and are less significant when several wave trains combine to generate a complex wave regime.

100. Beach response to seawalls is variable and appears to be influenced by a number of interdependent factors. Assessment of the potential impact of a seawall on a beach should be site-specific and consider the entire range of possible controlling factors.

101. Field studies of beach response to seawalls, and especially of associated processes, are limited. More studies are needed, and attempts to predict beach-seawall interactions from the existing data should be made with caution.

102. The most important factor in determining the potential impact of a seawall on the beach is whether there is long-term shoreline retreat. Such retreat is a function of sediment supply and/or relative sea level change. The impact a seawall has on a retreating shore is dependent on the geomorphic shore type. Unless such an erosive trend can be mitigated, the beach in front of a seawall will eventually disappear.

103. One of the most critical factors controlling the impact of a seawall on the beach is its position on the beach profile relative to the surf zone. All other things being equal, the further seaward the wall is, the more often and more energetically it can interact with the waves. The best place for a seawall, if one is necessary, is at the back of the beach where it provides protection against the largest of storms. By contrast, a seawall built out to the mean high water line may constantly create problems related to frontal and end scour. It may also eliminate alongshore access during winter months and high tides.

104. The majority of field studies indicate that most of the direct effects of seawalls on beaches are temporary or seasonal in nature and that seawalls do not impede the post-storm recovery process.

105. The most prominent example of lasting impacts of seawalls on the shore is the creation of end scour via updrift sand impoundment and downdrift wave reflection. Such end scour exposes the back beach, bluff, or dune areas to higher swash energies and erosion by waves.

106. There have been several cases where beaches in front of seawalls have been attacked by storm waves then never recovered. The reasons for this are poorly understood. Factors such as deficient sediment supply, wave exposure, steep offshore gradients, or small grain size may have been involved. When the above factors are evident locally, construction of a seawall may not be advisable.

107. Seawall design may be able to partially offset some of the potentially adverse effects of seawalls on beaches. Serious questions remain as to the significance of permeability differences. Very similar effects have been recognized and associated with both sloping, permeable walls and vertical

impermeable walls. Large storm waves may diminish any benefits conferred by lower reflectivity in wall design. It is recommended that further field studies be conducted before committing large sums of money to exotic seawall designs.

REFERENCES

Baba, M. and Thomas K. V. 1987. Performance of a seawall with a frontal beach. Proceedings of Coastal Sediments '87, American Society of Civil Engineers, 1051-1061.

Birkemeier, W. A. 1980. The effect of structures and lake level on bluff and shore erosion ir Berrigen County, Michigan, 1970-74. Coastal Engineering Research Center, Miscellaneous Report No. 80-2, US Army Corps of Engineers, 74 p.

Carter, C. H., Monroe, C. B., and Guy, D. E., Jr. 1986. Lake Erie shore erosion: the effect of beach width and shore protection structures. Journal of Coastal Research, 2 (1), 17-23.

Chiu, T. Y. 1977. Beach and dune response to hurricane Eloise of September 1975. Proceedings of Coastal Sediments '77, American Society of Civil Engineers, 116-134.

Davis, R. A., Jr., and Andronaco, M. 1987. Hurricane effects and post-storm recovery, Pinellas County, Florida (1985-1986). Proceedings of Coastal Sediments '87, American Society of Civil Engineers, 1023-1036.

Dean, R. G. 1986. Coastal armoring: effects, principles and mitigation. Proceedings of 20th Coastal Engineering Conference, American Society of Civil Engineers, 1843-1857.

Dean, R. G. 1988. In: Eroding Shorelines impose costly choices. Geotimes. 33 (5), 9-13.

Everts, C. H. 1985. Effects of small protective devices on beaches. California's battered coast: proceedings from a conference on coastal erosion, California Coastal Commission, 127-137.

Fitzgerald, D. M. 1980. Effects of intense storm at Winthrop Beach, Massachusetts. Shore and Beach, 48 (3), 6-19.

Fulton-Bennett, K. W. and Griggs, G. B. 1985. Coastal Protection and their effectiveness. Joint publication of California State Dept. of Boating and Waterways and Institute of Marine Sciences, University of California, Santa Cruz, 48 p.

Goud, M. R. and Aubrey, D. G. 1983. Survey of shoreline structures, Popponesset Beach, MA. Woods Hole Oceanographic Institution, Technical Report WHOI-83-14, 32 p.

Griggs, G. B. and Johnson, R. E. 1983. The impact of the 1983 storms on the coastline of northern Monterey Bay. California Geology 36, 163-174.

Griggs, G. B. and Tait, J. F. 1988. The effects of coastal protection structures on beaches along northern Monterey Bay, California. Journal of Coastal Research, Special Issue No. 4:93-111.

Jones, D. F. 1975. The effect of vertical seawalls on longshore currents. Unpublished Ph.D. Thesis, Department of Coastal and Oceanographic Engineering, University of Florida, Gainesville, FL, 118 p.

Komar, P. D. 1983. The erosion of Siletz Spit, Oregon. In: P. D. Komar (Ed.), CRC Handbook of Coastal Processes and Erosion, CRC Press, Inc., Boca Raton, FL, 65-76.

Komar, P. D. and Enfield, D. B. 1987. Short-term sea-level changes and coastal erosion. In: D. Nummedal, O. H. Pilkey, and J. D. Howard (Eds.), Sea-Level Fluctuation and Coastal Evolution, Society of Economic Paleontologists and Mineralogists, Special Publication No. 41, 17-27.

Kraus, N. C. 1988. The effects of seawalls on the beach: a literature review. Proceedings of Coastal Sediments '87, American Society of Civil Engineers, 945-960.

Kriebel, D. L. 1987. Beach recovery following hurricane Elena. Proceedings of Coastal Sediments '87, American Society of Civil Engineers, 990-1005.

Kriebel, D. L., Dally, W. R., and Dean, R. G. 1986. Beach profile response following severe erosion events. Coastal and Oceanographic Engineering Department, UF/COEL-86/016, University of Florida, Gainesville, FL.

Lin, M-C., Wu, C-T., Lu, Y-C., and Liang, N-K. 1986. Effects of short-crested waves on the scouring around the breakwater. Proceedings of 20th Coastal Engineering Conference, American Society of Civil Engineers, 2050-2064.

McDonald, H. V. and Patterson, D. C. 1985. Beach response to coastal works, Gold Coast, Australia. Proceedings of 19th Coastal Engineering Conference, American Society of Civil Engineers, 1522-1538.

McDougal, W. G., Sturtevant, M. A., and Komar, P. D. 1987. Laboratory and field investigations of the impact of shoreline stabilization structures on adjacent properties. Proceedings of Coastal Sediments '87, American Society of Civil Engineers, 961-973.

Pilkey, O. H. 1981. Geologists, engineers, and a rising sea level. Northeastern Geology, 3 (3/4), 150-158.

Pilkey, O. H. 1988. In: Eroding shorelines impose costly choices. Geotimes, 33 (5), 9-13.

Sato, S., Tanaka, N., and Irie, I. 1969. Study on scouring at the foot of coastal structures. Proceedings of 11th Coastal Engineering Conference, American Society of Civil Engineers, 579-598.

Sayre, W. O. 1987. Coastal erosion on the barrier islands of Pinellas County, west-central Florida. Proceedings of Coastal Sediments '87, American Society of Civil Engineers, 1037-1050.

Sexton, W. J. and Moslow, T. F. 1981. Effects of Hurricane David, 1979, on the beaches of Seabrook Island, South Carolina. Northeastern Geology, 3 (3/4), 297-305.

Silvester, R. 1977. The role of wave reflection in coastal processes. Proceedings of Coastal Sediments '77, American Society of Civil Engineers, 639-652.

Silvester, R. 1974. Coastal Engineering. Elsevier Scientific Publishing Company, Amsterdam, The Netherlands.

Toyoshima, O. 1979. Effectiveness of seadikes with rough slope. Proceedings of 16th Coastal Engineering Conference, American Society of Civil Engineers, 2528-2539.

Toyoshima, O. 1985. New type of blocks for seawall slope protection. Proceedings of 19th Coastal Engineering Conference, American Society of Civil Engineers, 2537-2545.

Walton, T. L. and Sensabaugh, W. 1979. Seawall design on the open coast. Florida Sea Grant College, Report No. 29, 24 p.

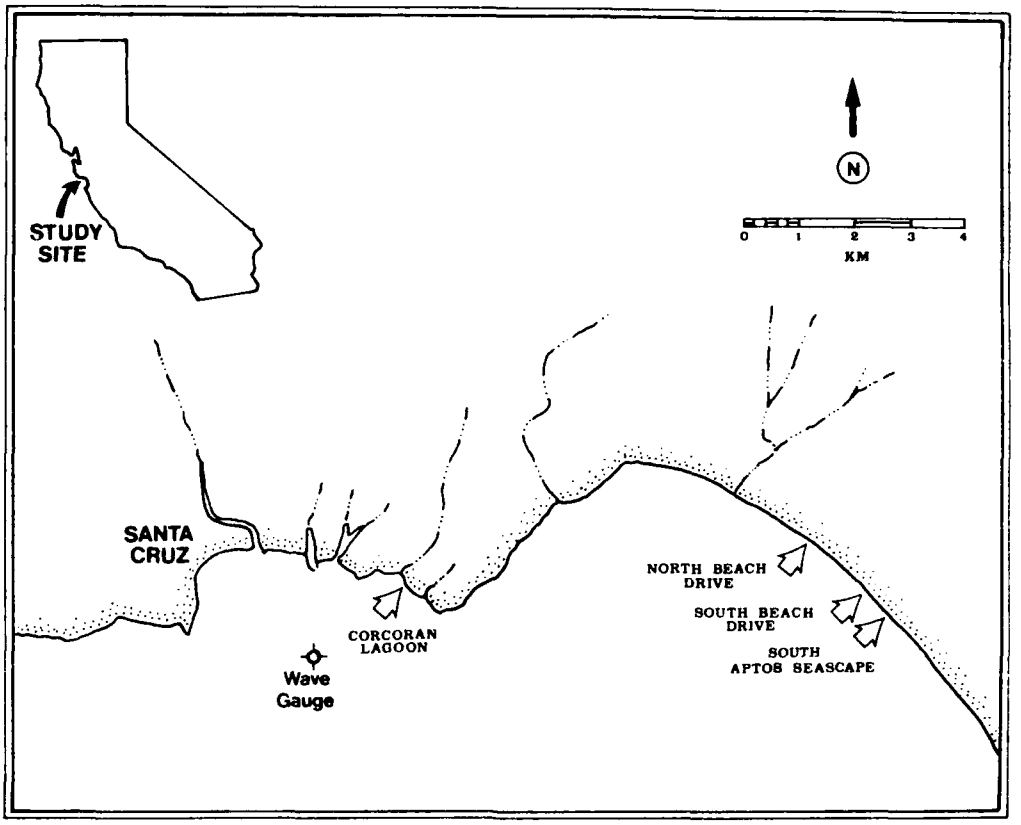


Figure 1. Location map of Griggs and Tait 1986-1987 study area, Monterey Bay, California

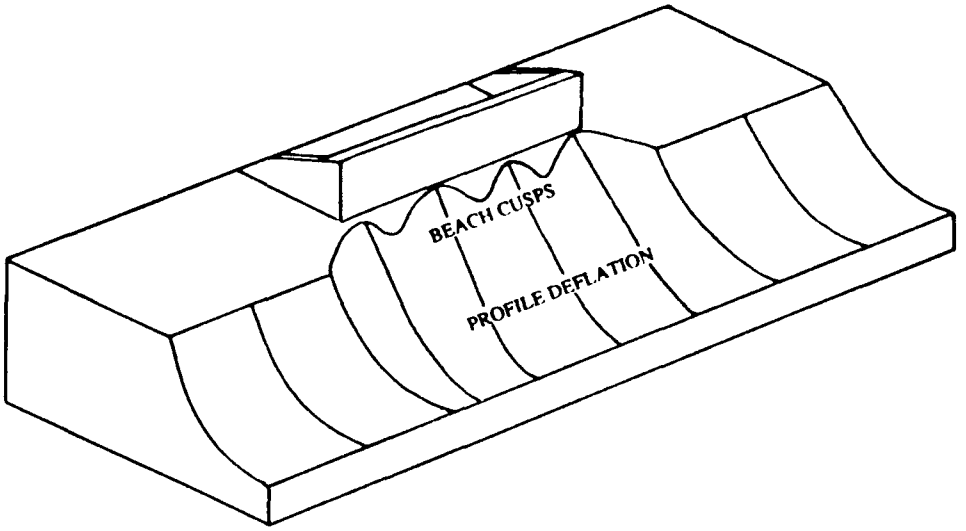


Figure 2. Types of beach response observed by Griggs and Tait before berm retreats past seawall

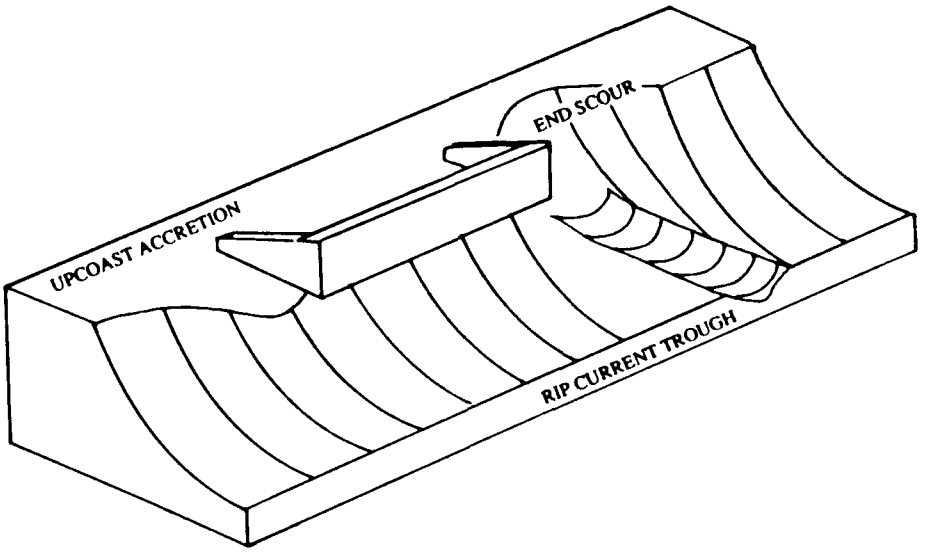


Figure 3. Types of beach response observed by Griggs and Tait after berm retreats past seawall

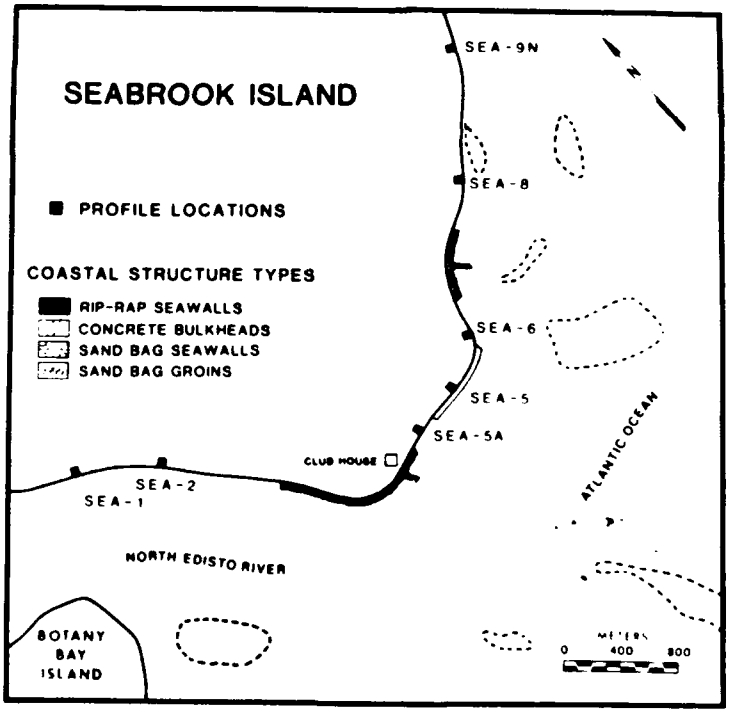


Figure 4. Location map of profile stations and structures in Sexton and Moslow study of the effects of Hurricane David on Seabrook Island. Note location of profiles Sea-5 and Sea-6 discussed in text. (From Sexton and Moslow 1981)

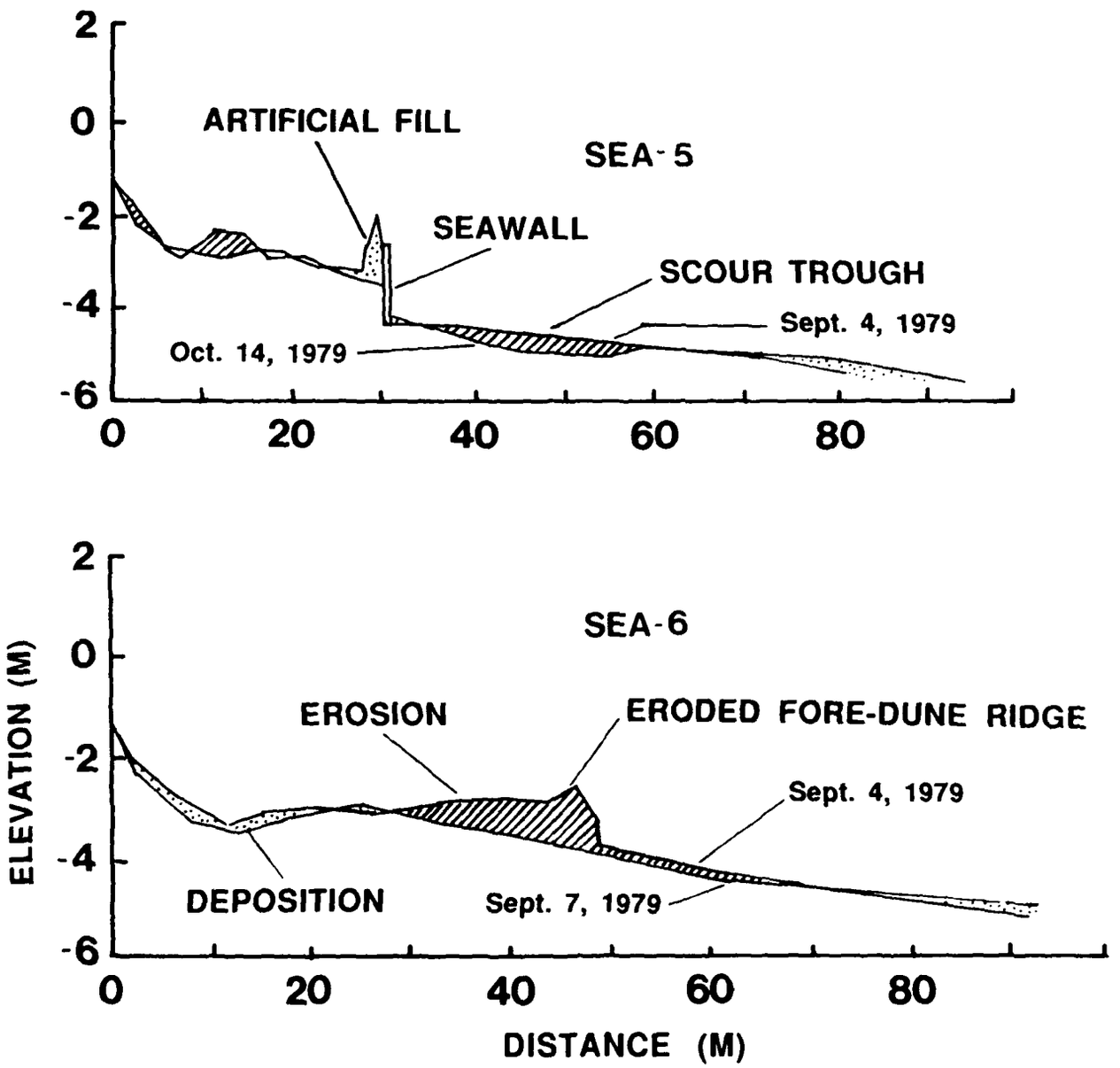


Figure 5. Pre- and post-storm profiles, Seabrook Island (Sexton and Moslow 1981)

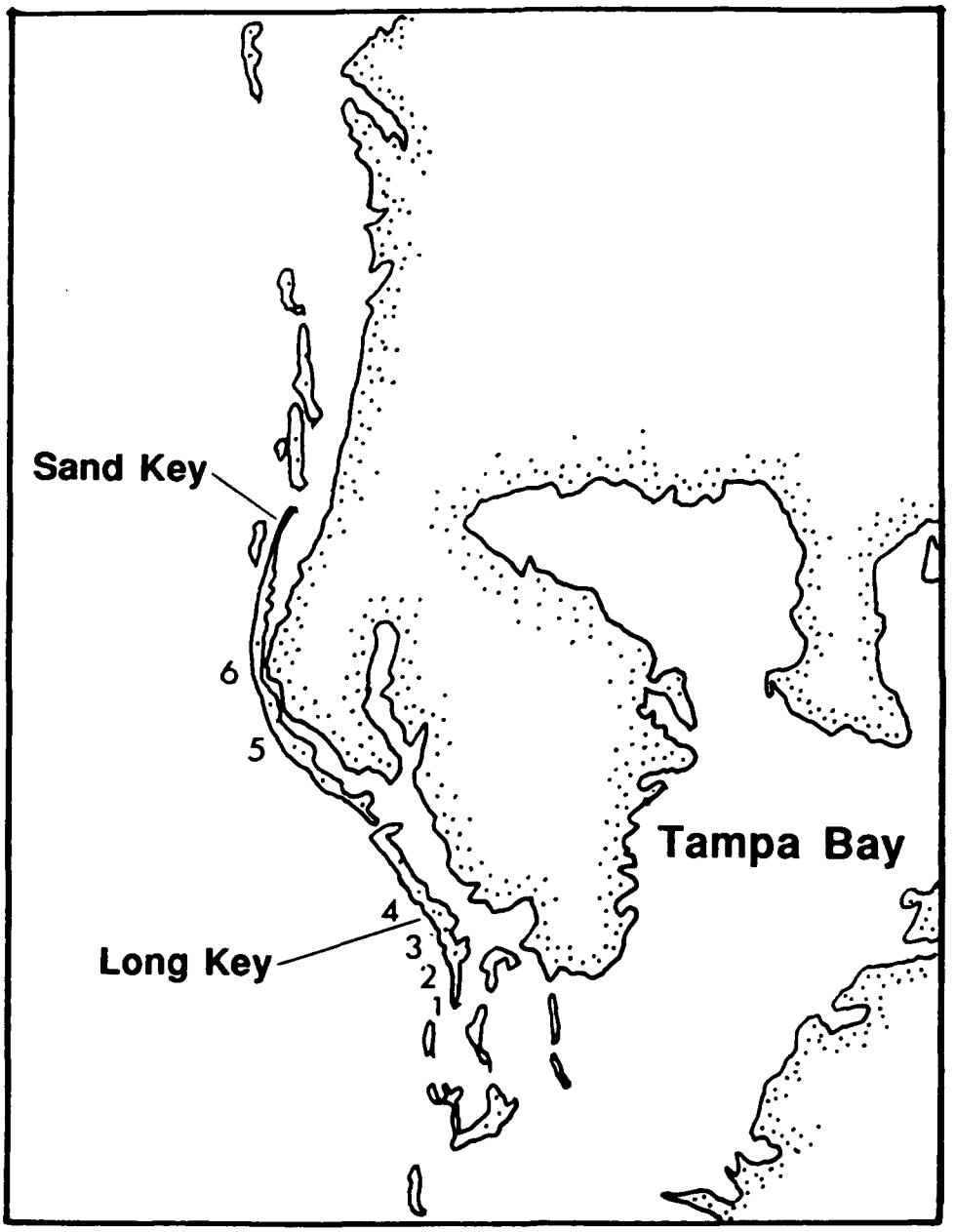


Figure 6. Location map for west-central Florida hurricane studies (Davis and Adronaco 1987)

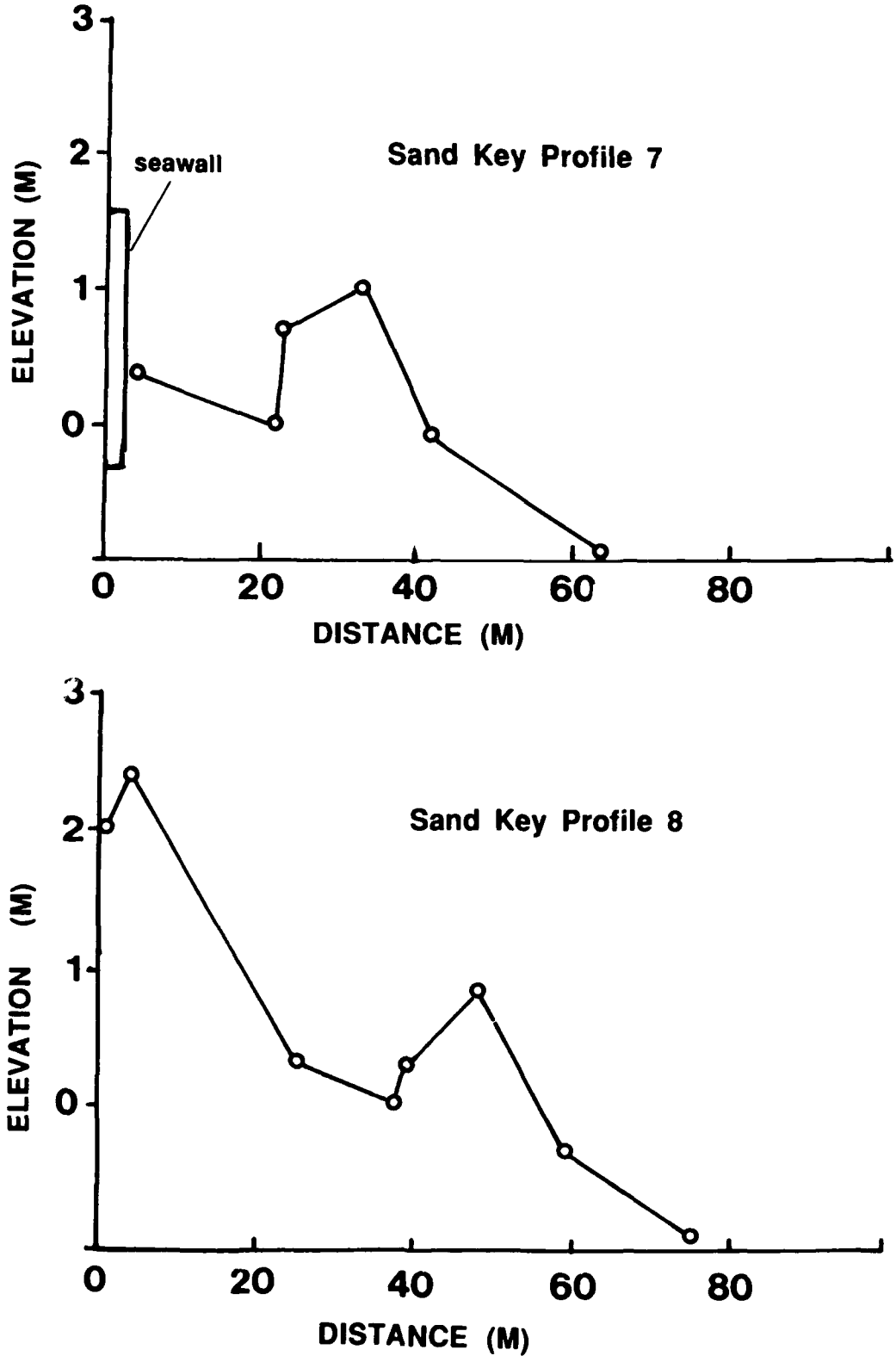


Figure 7. Post-storm profiles at Sand Key, Florida (Davis and Andronaco 1987)

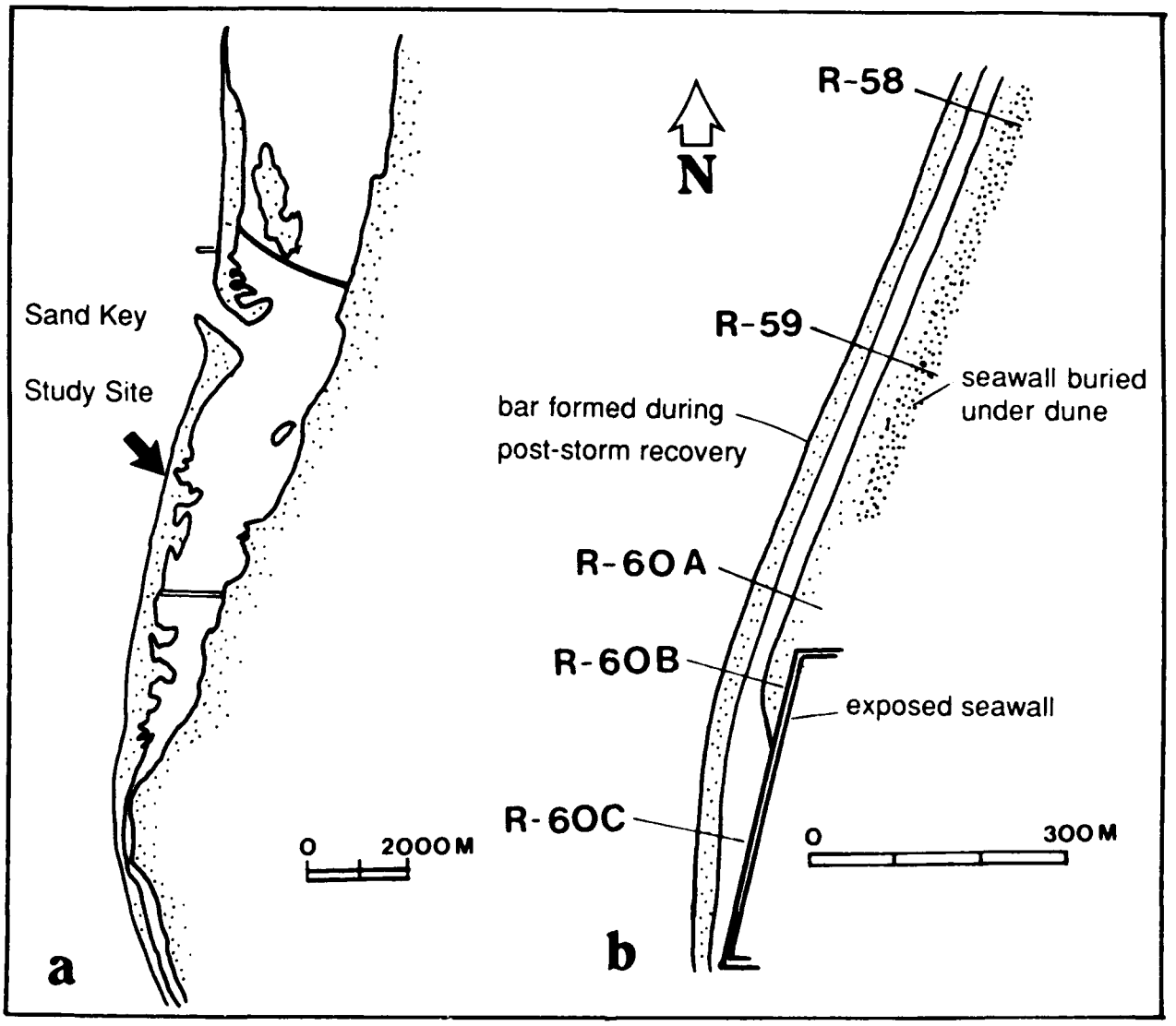


Figure 8. Site map for Sand Key, Florida study (Kriebel 1987)

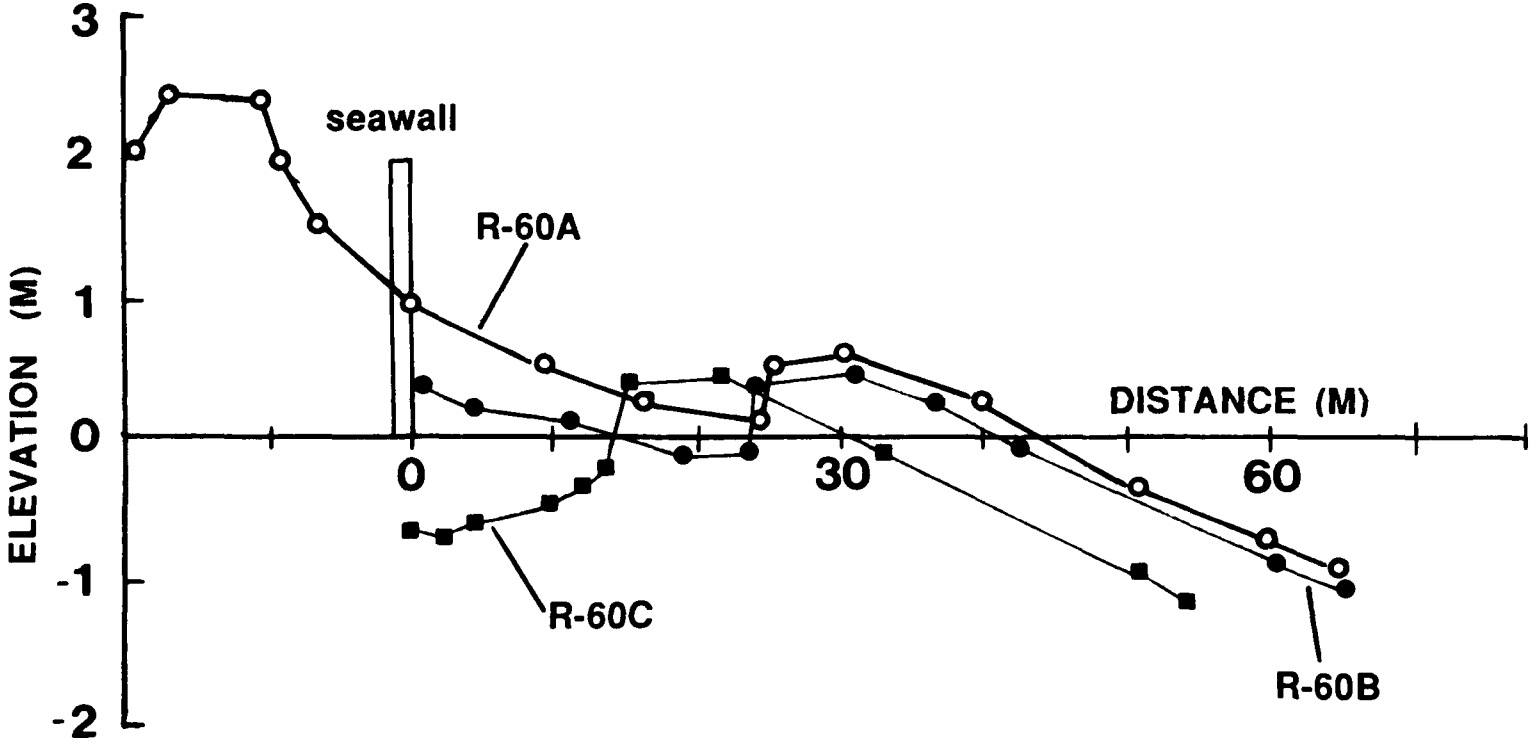


Figure 9. Post-Hurricane Elena profiles at Sand Key (Kriebel et al. 1986)

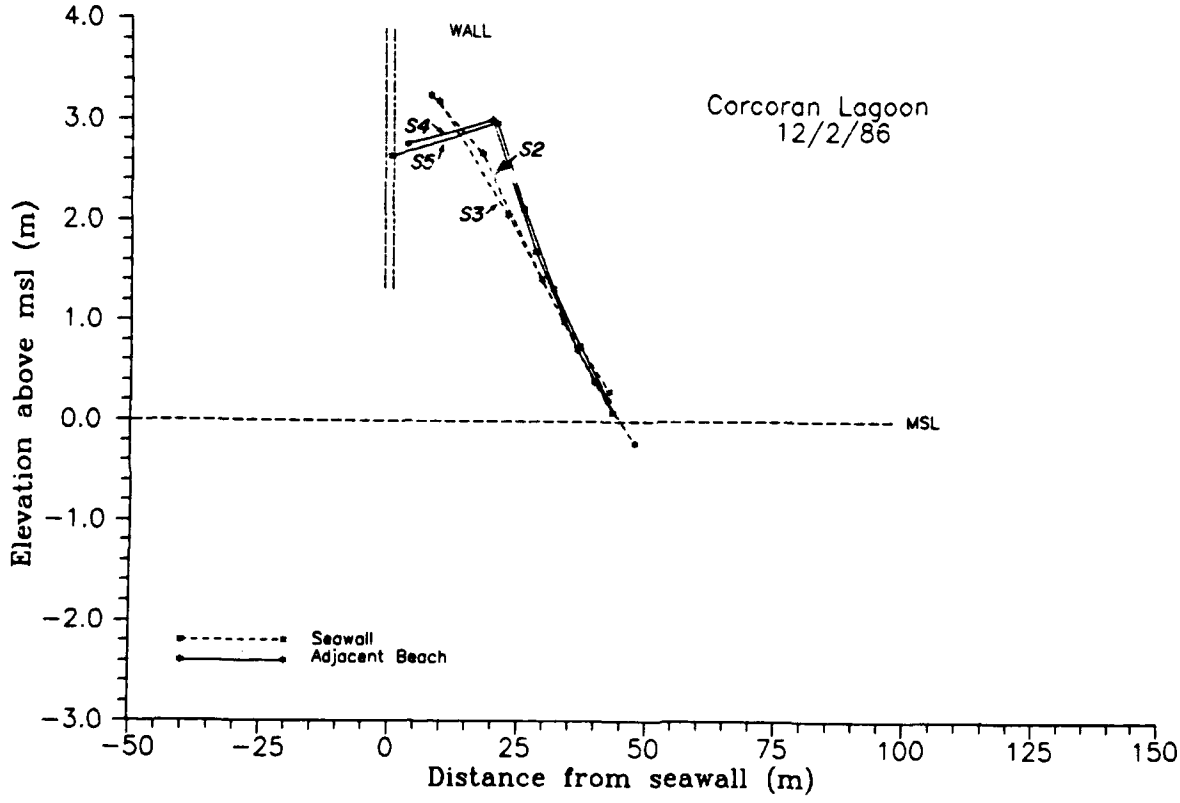


Figure 10. Beach profiles at Corcoran Lagoon, Monterey Bay, showing deflation of summer berm in front of seawall (dashed lines) and persistence of berm on adjacent natural beach (solid lines). (From Griggs and Tait 1988)



Figure 11. Effects of a revetment at New Brighton State Beach, Monterey Bay, California (Griggs and Tait 1988)



Figure 12. South Beach Drive, Monterey Bay in early winter (Griggs and Tait 1988)

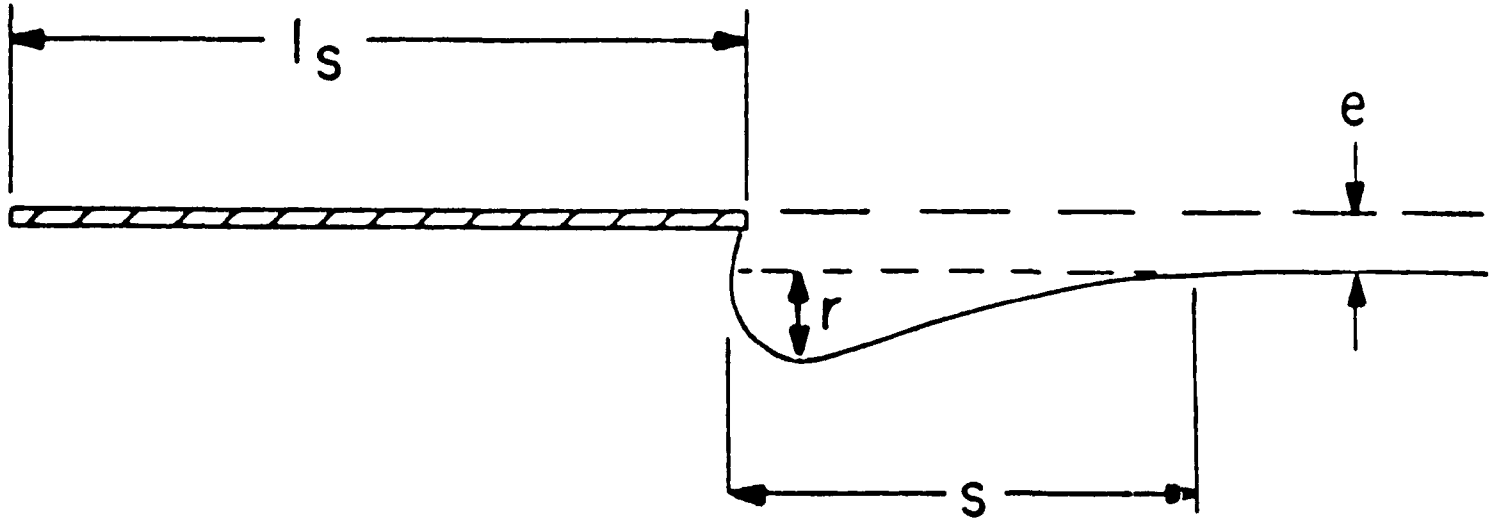


Figure 13. Typical scour pattern at end of seawall (McDougal et al. 1987)

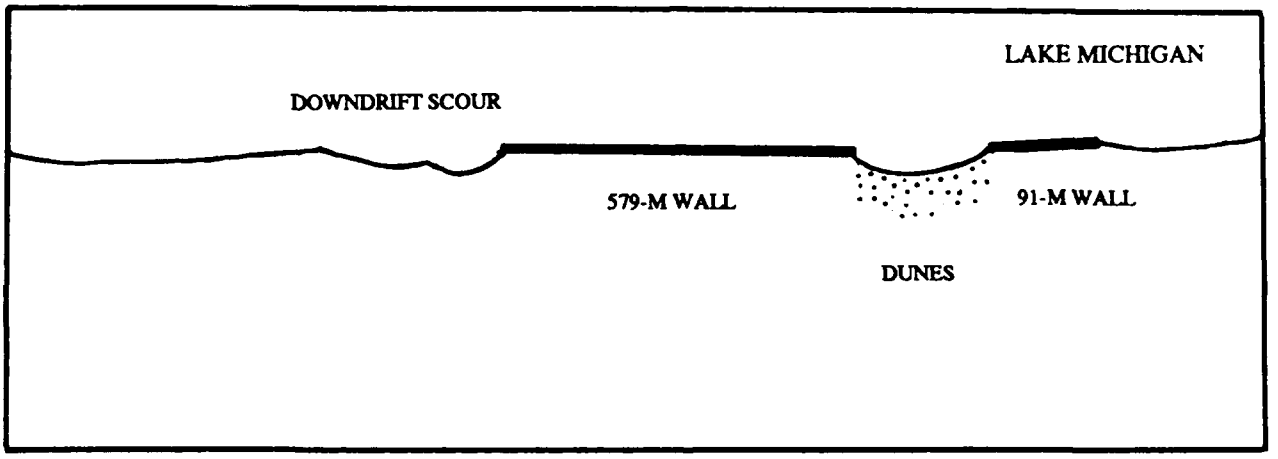


Figure 14. Site map of Birkemeier's Lake Michigan study. Downdrift cut, dune area, and seawalls are depicted. (After Birkemeier 1980)

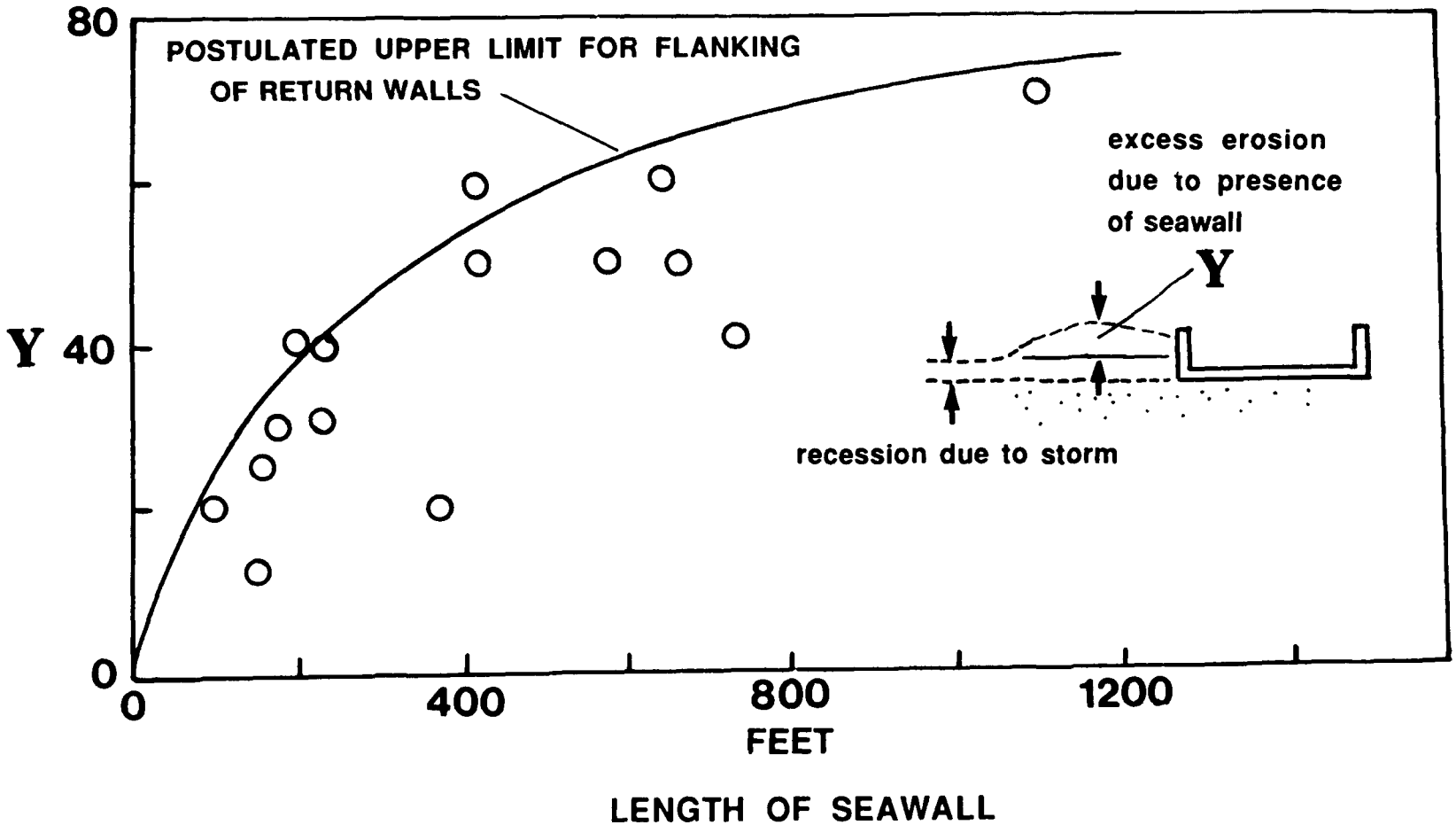


Figure 15. Graph of seawall length versus end scour (Walton and Sensabaugh 1979)
(To convert feet to meters, multiply by)



Figure 16. End scour at Aptos seascape seawall, Monterey Bay, California (Griggs and Tait 1988)

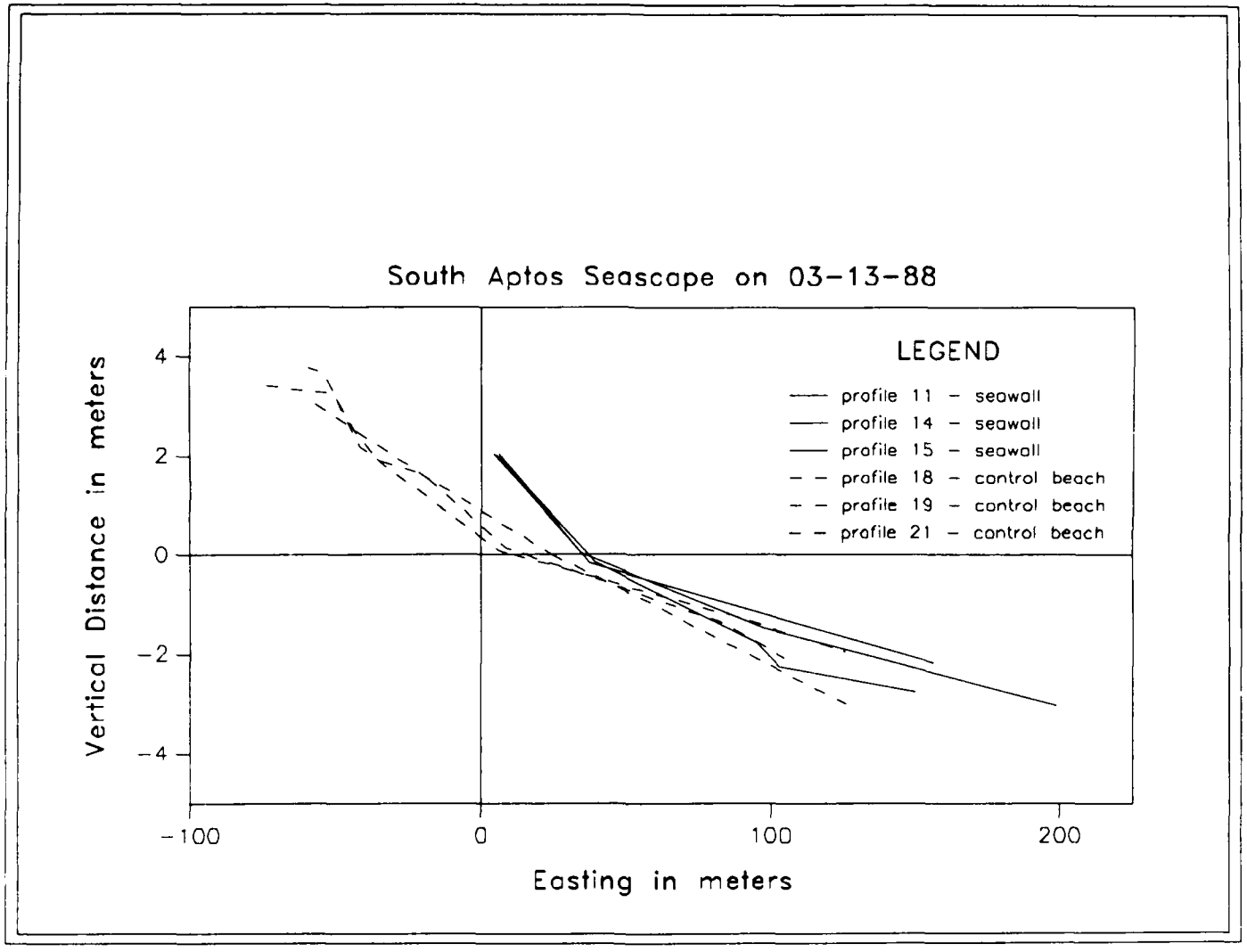


Figure 17. Winter beach profiles from the Aptos Seascape seawall site in northern Monterey Bay, California

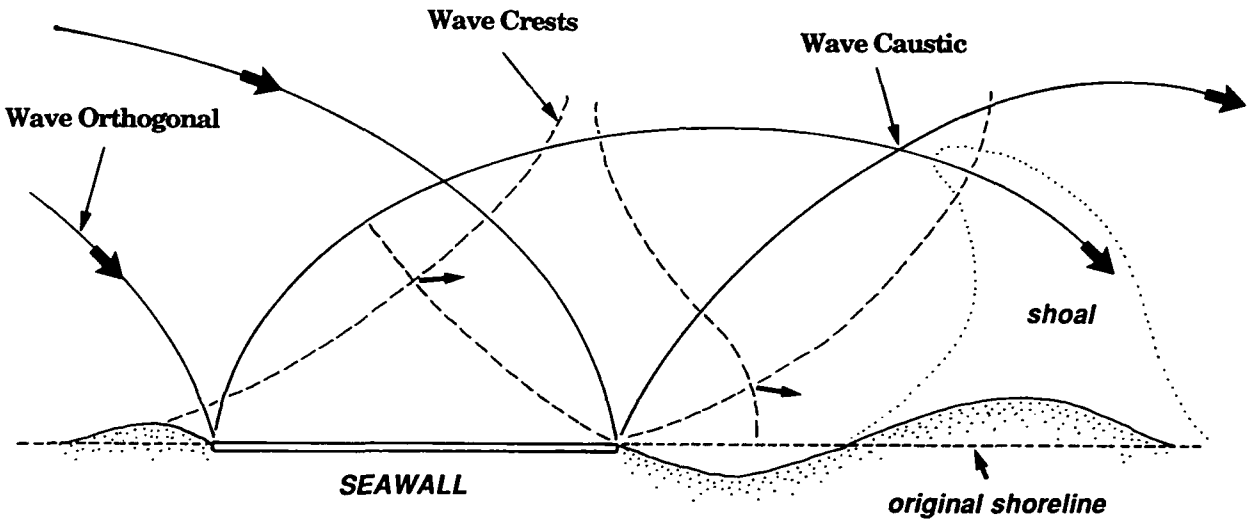


Figure 18. Short-crested wave system generated by obliquely reflected waves summing with incident waves. Areas of scour are produced in the vicinity of the wall and deposition occurs further downcoast. (From Silvester 1977)



Figure 19. Photograph of wave reflected from end of seawall, South Aptos Seascape, Monterey Bay (Griggs and Tait 1988)

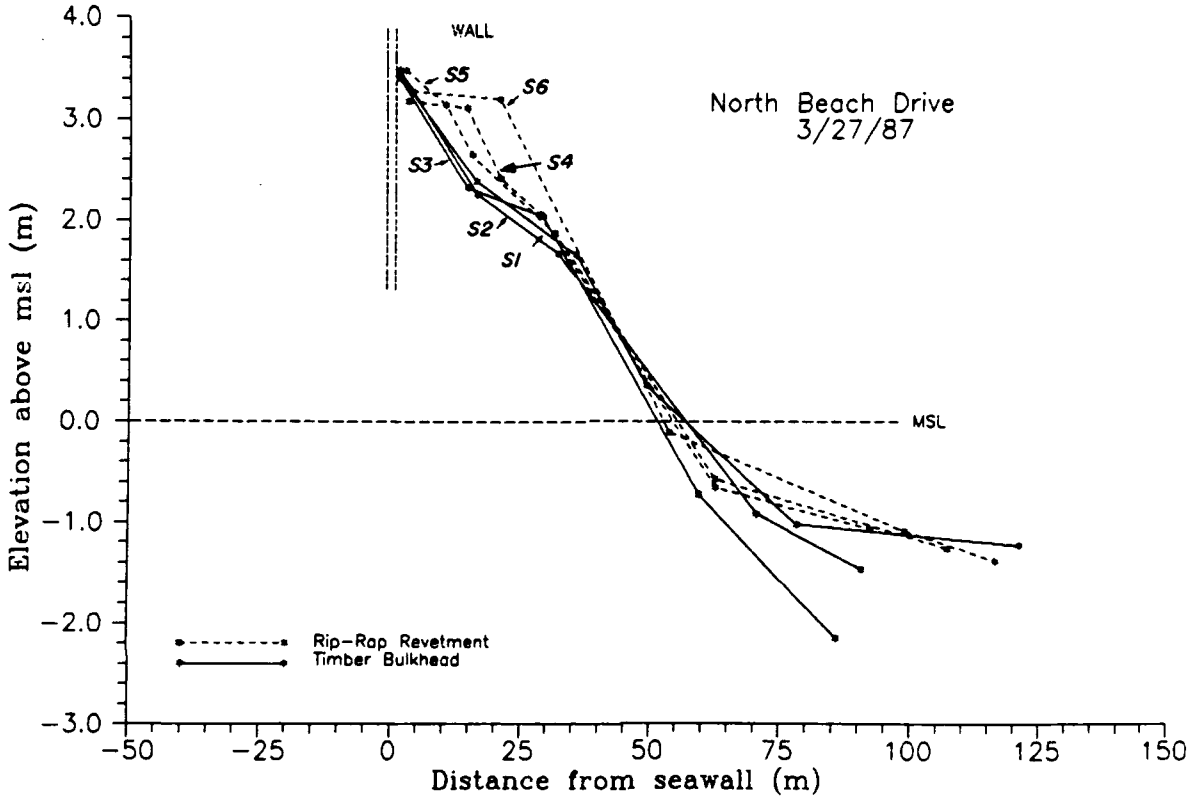
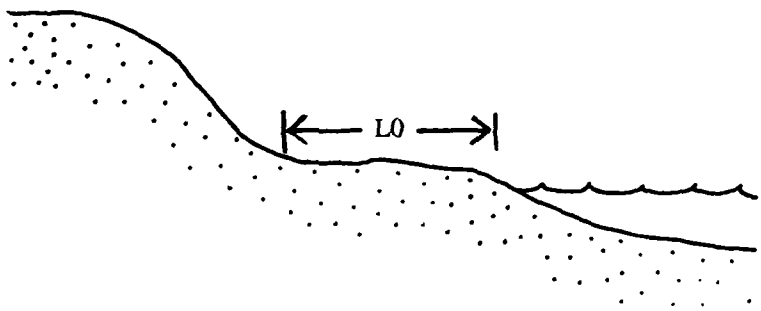


Figure 20. Beach profiles at North Beach Drive. Note persistence of wide berm in front of permeable revetment (dashed lines) in contrast to absence of berm in front of impermeable bulkhead (solid lines). (From Griggs and Tait 1988)

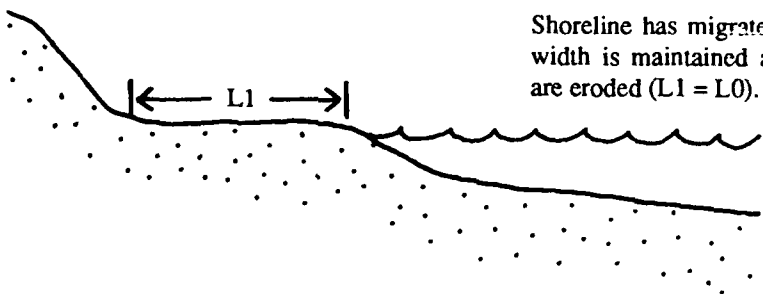
LONG-TERM EFFECTS OF SEAWALL ON RETREATING SHORE

CASE I: ERODIBLE BLUFFS OR DUNES, SEDIMENT DEFICIENCY AND SEA LEVEL RISE, WALL AT BACK BEACH.

INITIAL SHORE PROFILE

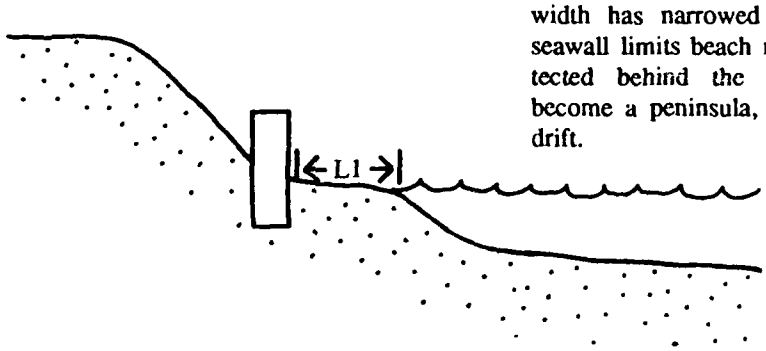


SHORE PROFILE AFTER SHORELINE RETREAT



Shoreline has migrated landward but beach width is maintained as the bluffs or dunes are eroded (L1 = L0).

SHORE PROFILE AFTER SHORELINE RETREAT WITH SEAWALL



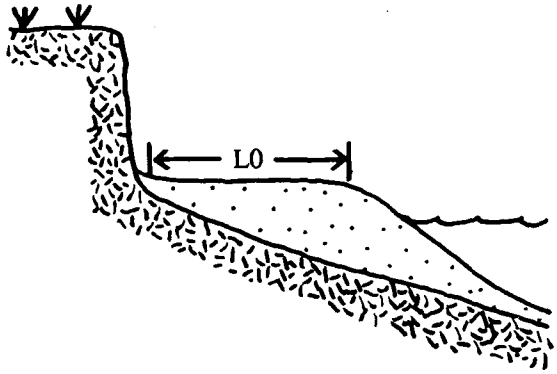
Shoreline has migrated landward and beach width has narrowed (L1 < L0) because seawall limits beach retreat. The area protected behind the wall can eventually become a peninsula, obstructing longshore drift.

Figure 21. Long term effects of a seawall on a retreating shoreline

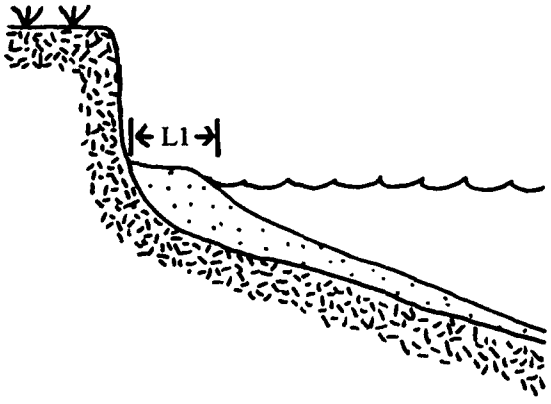
LONG-TERM EFFECTS OF SEAWALL ON RETREATING SHORE

CASE II: RESISTANT SEACLIFF, SEDIMENT DEFICIENCY AND SEA LEVEL RISE, WALL AT BASE OF CLIFF.

INITIAL SHORE PROFILE

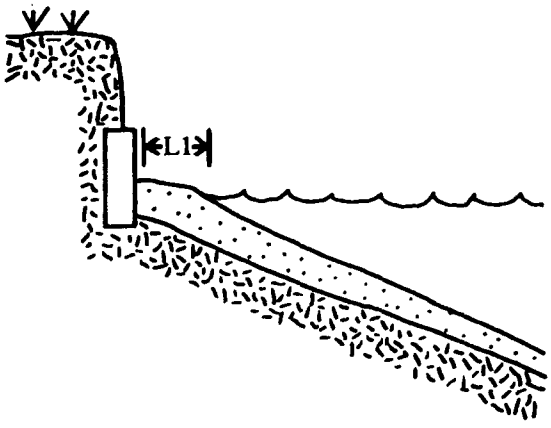


SHORE PROFILE AFTER SHORELINE RETREAT



Shoreline migrates landward and beach narrows because seacliff limits beach retreat (L1 < L0).

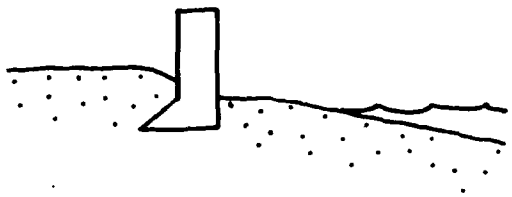
SHORE PROFILE AFTER SHORELINE RETREAT WITH SEAWALL



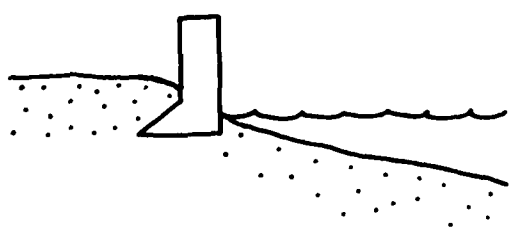
Seawall has approximately the same effect on the beach as would the seacliff (L1 < L0). If the wall is more resistant than the seacliff, the seawall could become a small headland over time. If the shoreline is stable or advancing, the wall has little effect.

Figure 22. Long term effects of a seawall on a retreating shoreline

WALL BUILT TOO FAR SEAWARD ON BEACH PROFILE



Seawall is placed well seaward on beach profile; a narrow summer berm exists. The beach in front of the wall is very sensitive to changes in sediment supply or sea level.



If there is net shoreline retreat, the area behind the wall may become a peninsula, obstructing longshore transport. Under seasonal changes, the wall may similarly lose the beach in front of it, project into the surf zone, impound littoral drift, promote downcoast erosion, and obstruct alongshore beach access (Griggs and Tait).

Figure 23. Long term effects of building a seawall well seaward on the beach profile